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SOVIET INSTRUMENTATION AND CONTROL TRANSLATION SERIES

Measurement Techniques

(The Soviet Journal *Izmeritel'naya Tekhnika* in English Translation)

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Measurement Techniques

A translation of Izmeritel'naya Tekhnika, a publication of the Academy of Sciences of the USSR

Russian Original Dated February, 1961

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METROLOGICAL TASKS IN AGRICULTURE

N. M. Karelin

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 1-2, February, 1961

The January plenary session of the CPSU (Communist Party of the Soviet Union) Central Committee worked out a program for a further rise in all the branches of agricultural production. The resolution of the CPSU Central Committee plenary session states: "Higher rates of agricultural development are now required in the interests of communist construction and a steady rise in the well-being of the people. The present task consists in making agricultural production always lead the requirements of the population."

The solution of this problem requires a high level of overall mechanization, automation, and electrification of agriculture, as well as a rapid advancement of agricultural science.

A rapid development of agricultural production is impossible without the application of the appropriate measuring equipment for determining the quality of production and checking the basic characteristics in the operation of machines and plants, in the use of fuel, threshing of grain, and other characteristics.

Agricultural science cannot develop without the application of measuring instruments for determining the properties of the soil, sorting production, determining the quality of fertilizers, predicting weather conditions, estimating the characteristics of agricultural machinery, etc.

In agricultural production and science, measuring instruments are used for investigating plants, the soil, the air above the ground, for determining the quality of production, for testing tractors and machines, in animal husbandry and veterinary services, etc. Thus, in delivering and storing grain it is necessary to use hygrometers, scales, hondrometers, etc.; for determining the development of physical and chemico-biological processes in animals and plants various thermometers are used, mostly electrical, including thermocouples with semiconductor transducers, etc.; for determining the chemical composition of soil pH-meters are used, for determining the fat content of milk—butyrometers, for determining the traction effort of a tractor and the distance covered by it—ergometers, for automatically checking the depth of the soil turned over in the plowing—furrow meters, for measuring the humidity of air—psychrometers and many other instruments.

The resolution of the CPSU Central Committee plenary session states: " ... At present our country has the possibility of raising the capital investment above the level foreshadowed in the Seven-Year Plan for agriculture, and for industries supplying agriculture, those producing tractors and agricultural machinery, mineral fertilizers and building materials.

"In allocating additional means for the development of agriculture the Party aims at providing conditions which would make agriculture independent of the vagaries of Nature. Agricultural production must be organized in such a manner that it should always provide under any climatic conditions the produce required by the country for a complete satisfaction of the people's requirements."

The fulfilment of this task requires a further development of agricultural measuring equipment and its introduction in production and research.

The instrument-making industry should meet the requirements of agriculture not only in instruments of a general industrial application, but should also develop special instruments for use in agriculture and based on the latest achievements of science and technology, utilizing in their instruments semiconductors, radioactive preparations, ultrasonic and infrared radiations, etc.

In connection with the large irrigation program adopted by the CPSU Central Committee plenary session it is necessary to improve the existing and develop new methods and means of measuring the flow of water.

The development of agricultural automation requires the production of instruments for the automation of such stationary equipment as threshers, grain-cleaning and drying plants, equipment for making peat-compost pots, etc.

In order to determine the quantity of oil products used in operating agricultural machinery it is necessary to establish a method for measuring these products and develop the appropriate measuring equipment for use under field conditions.

The agricultural scientific organizations have the task of drawing conclusions from the experience gained in using instruments and means of automation in agriculture and developing appropriate specifications for the instrument-making industry, as well as introducing checking and control instruments produced by our industry into animal husbandry and arable farming.

The special conditions under which instruments are used in agriculture make it necessary to equip these instruments with a wider range of spare components and units than normally supplied to industrial plants.

Appropriate literature should be issued on the problems of using measuring equipment in agriculture, and technical information on this subject should be developed on a wide scale. Instruments intended for use in agriculture should be supplied with detailed technical instructions.

It is necessary to provide facilities for repairing instruments in agricultural regions and districts. These facilities should be established as close to the collective and state farms as possible by setting up repair workshops at the RTS (Tractor Repair Stations) and providing mobile workshops on trucks for repairing instruments on the spot.

The Ministries of Higher and Secondary Technical Education of the Union Republics should start training on a large scale widely specialized instrument-maintenance personnel (engineers and technicians) for agriculture.

Ensuring a uniform, accurate and correct use of measures and measuring instruments is a prerequisite in modern agricultural production. This task should be fulfilled by the scientific research institutes and state inspection laboratories for measuring equipment (GKL) of the Committee of Standards, Measures and Measuring Instruments attached to the USSR Council of Ministers.

In recent years the institutes have developed and produced reference means and methods of checking instruments used in agriculture. They include reference thermo-vacuum equipment for checking and calibrating hygrometers and accurate measurement of the moisture in grain with an error of measurement not exceeding ± 0.1% of moisture; a fully mechanized mobile weighing installation for checking truck scales up to 10 tons, whose use has trebled the productivity of labor in checking these scales and at the same time freed 3-4 workers for other employment; a stationary mechanized equipment for checking freight scales up to 1 ton, which has raised considerably the productivity of labor and can be widely used in repair workshops; a mobile test laboratory installed on a GAZ-69 truck which makes it possible to check various instruments on the spot, as well as several other reference methods and installations.

It should be noted that the greater part of these instruments is used to a very limited extent by the GKLs. The production of this equipment should be greatly increased in the near future.

The precision measuring methods and instruments developed by the institutes, such as the full immersion chain areometer, non-mercury piston barometer, reference dynamometers, vacuum gauges, micromanometers, linear glass thermometers, etc. should find a wide application in agricultural scientific-research institutions.

The instrument-making plants should mass-produce these instruments.

The GKLs should organize their work in such a manner as to become real metrological centers of the agricultural regions and districts which they serve. For this purpose the GKLs should increase the range of instruments tested by them in order to satisfy completely the requirements of their regions and districts; they should also provide expert advice on the measuring methods and utilization of instruments, extend the information supplied by them on measurement equipment, analyze and generalize with the assistance of repair establishments and workshops the experience gained in the use of instruments, units and components, and study the defects in their construction in order to submit proposals to the instrument-making plants for their improvement, etc.

The GKLs should strengthen their control over the condition and correct utilization of instruments, paying special attention to the equipment used for checking deliveries of collective and state farms to storage depots, i.e., hygrometers, butyrometers, scales, etc.

There can be little doubt that the metrological personnel will make its contribution to the fulfilment of the tasks raised at the January plenary session of the CPSU Central Committee.

ERRORS IN CHECKING LINEARITY OF LARGE PLATES

K. I. Abadzhi

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 3-6, February, 1961

Step-by-step methods are being used on an increasingly wide scale for checking linearity and flatness of large-size guide-rails and plates. Side by side with the development of the interference, optical, hydrostatic and other methods [1, 2], step-by-step methods are also being developed and improved. These improvements include new designs for stepping bridges produced here and abroad [3], and the study and perfection of data-processing methods for this type of measurement [4, 5]. However, the evaluation of errors for various methods of measuring linearity and flatness of large plates and guide-rails has not as yet been sufficiently studied or reported in the technical press.

From the point of view of the resulting error evaluation, all the methods for checking linearity and flatness of large plates and guide-rails may be divided into two groups: methods based on the step-by-step principle and those based on comparing the controlled object with a reference sample.

The step-by-step method is characterized by a chain connection between all the component dimensions, and a coupling between each preceding and succeeding step; this characteristic determines the formation of the limiting error when the above method of measurement is used.

Other methods are not characterized by the above chain relationship, although some of them are externally similar to the step-by-step method. The measuring bridge or a rack with a mark is also displaced in certain other methods along the controlled direction and is placed consecutively at equally spaced points. In other methods gaps between the controlled and reference plates (for instance, a straightedge) are measured at determined equally spaced points or cross sections. Other methods are based on measuring curvatures with respect to an ideal straight line (for instance, in the Linnik interferometer). In all these methods there is no chain relationship between the measurement points or cross sections, and the nature of the measurement error formation will differ from that in the step-by-step method.

In the step-by-step method the measuring instrument may be placed directly on the stepping bridge [3, 6, 7], but it can also be mounted separately. Measurements made by means of a separately mounted autocollimator sighted on a mirror fixed to a stepping bridge which is displaced in the controlled direction [6, 7] may serve as an example of the latter method. The step-by-step method is illustrated in Fig. 1. The nature of the mutual relationship between the separate readings in the step-by-step method is illustrated by the graph in Fig. 2.

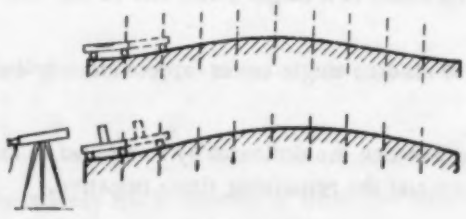

Fig. 1.

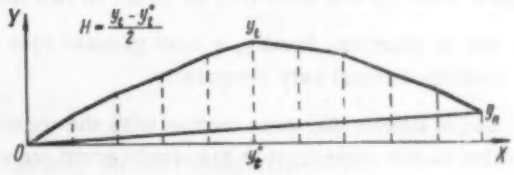

Fig. 2.

The error of each measurement by means of the stepping bridge is determined by various factors: by the calibrations of the measuring instrument, error of adjustment at each point (the presence of dirt on the plate, micro- and macro-irregularities of the surface), the length of the step, the readout error which depends on various factors, etc. However, in this instance we are not interested in the value of a single error, but in the nature of its accumulation. Let us examine the problem of its accumulation.

The measurement data processing table contains the following columns:

x_i are the abscissas of the stepping bridge reference points along the controlled direction;

m_i are the measuring instrument readings in divisions;

p_i are the measuring instrument readings in mm ($p_i = m_i\tau$; where τ is the minimum calibration of the instrument in mm; if the measuring instrument has an angular calibration, the latter should be expressed in radians and multiplied by the length l of the stepping instrument base);

y_i are the ordinates of the broken line;

y_i° are the consecutive ordinates of the points along the straight line connecting the ends of the broken line;

h_i are the consecutive differences of ordinates ($h_i = y_i - y_i^\circ$);

n is the number of steps;

Δp is the single error.

For a systematic error Δp = const and, therefore, a constant systematic single error which accumulates during measurement deflects the whole broken line either up or down.

The connecting straight line deviates together with the broken line. Hence, an accumulated systematic error at cross section t will distort equally the ordinate of the broken line y_t and the corresponding ordinate of the connecting straight line y_t°. It is obvious, therefore, that the difference between the ordinates is not distorted by a systematic accumulated error. In order to preserve the sign of the systematic error it is necessary in displacing the stepping bridge not to turn it through 180°, not to change the position of the readout instrument or its zero setting, etc.

If the single error is random and changes its sign more or less regularly, remaining in its absolute value about the same, we have

$$\Delta y_t = \pm\Delta p; \quad \Delta y_t^\circ = \pm\Delta p; \quad \Delta h_{t_{max}} = \pm 2\Delta p. \tag{1}$$

Since linearity is equal to half the maximum difference between the ordinates (for a uniform linearity) or to half the difference between the maximum linear characteristics (for a complex linearity) [5], the linearity measurement error will be accordingly decreased to

$$\Delta_{lim} = \frac{\Delta h_{t_{max}}}{2} = \pm\Delta p, \tag{2}$$

or

$$\Delta_{lim} = \frac{\Delta h_1 + \Delta h_2}{2} = \pm 2\Delta p, \tag{3}$$

i.e., even in the worst case, when the errors of the broken and connecting straight-line ordinates at cross section t have opposite signs, the limiting error in measuring linearity will be equal to a single error, and in the case of a complex linearity the error will be equal to two single errors.

Let us examine, finally, a most general case when the signs of random single errors (approximately equal in their absolute values) vary irregularly.

Let us denote the cross section with the maximum difference between the ordinates by t, and let us assume that prior to this cross section the single errors were m times positive and the remaining times negative.

We can then write

$$\Delta y_t = m\cdot\Delta p + (t-m)\cdot(-\Delta p) = (2m-t)\,\Delta p. \tag{4}$$

Let us assume that following cross section t up to the end of the controlled line the positive single error occurred k times.

The accumulated error at the last point can then be written as

$$\Delta y_n = (2m-t)\,\Delta p + k\cdot\Delta p + (n-t-k)\cdot(-\Delta p) = \\ = (2m+2k-n)\,\Delta p. \tag{5}$$

The error of the ordinate at point t on the connecting straight line will be

$$\Delta y_t^{\circ} = \frac{t}{n} y_n = \frac{t}{n} (2m+2k-n)\, \Delta p. \tag{6}$$

Then the error of the maximum difference between the ordinates at cross section t will amount to

$$\Delta h_t = \Delta y_t - \Delta y_t^{\circ} = 2\left(m - t\,\frac{m+k}{n}\right)\Delta p. \tag{7}$$

The maximum possible error of this linearity measurement method is

$$\Delta_{max} = \left(m - t\,\frac{m+k}{n}\right)\Delta p. \tag{8}$$

Assuming that errors which follow a normal distribution law add as their squares, the limiting error of this linearity measurement method can be written as

$$\Delta_{lim} = \Delta p \sqrt{m - t\,\frac{m+k}{n}}\,. \tag{9}$$

The above analysis shows that the most unfavorable case will exist when the errors with one sign occur at all the steps up to the point with the greatest curvature, and following that point the errors have the opposite sign. The point with the greatest curvature then occurs in the middle of the controlled line, and the error attains a maximum, since the coefficient for a single error increases to $\sqrt{n}/2$ (n is the number of steps).

Let us take as actual example a plate or a guide-rail 10 m long, and the instrument step as l = 500 mm, then n = 20. Let us assume that the largest difference between the ordinates is in the middle of the distance, i.e., t = 10. Let us also assume that m = 10, k = 0, then $\Delta_{lim} \approx 2.24\ \Delta p$. If for the same plate an instrument with a step of l = 250 mm is used, we shall have n = 40 and $\Delta_{lim} \approx 3.16\ \Delta p$. Such a distribution of the random error signs is not likely to occur. Let us assume that the ratio of the number of single errors with one sign to that with the opposite sign amounts to 2 : 3. Then for a most frequently occurring position of the maximum curvature approximately in the middle of the controlled line we can write

$$\frac{m+k}{n-(m+k)} = \frac{2}{3}, \text{ and } \frac{m+k}{n} = \frac{2}{5}, \quad m+k = \frac{2n}{5}.$$

Assuming

$$m = \frac{3n}{10} \text{ and } k = \frac{n}{10},$$

we obtain

$$\Delta_{lim} = \Delta p \sqrt{0.1\,n}.$$

For a relatively small number of steps (for instance n = 20) the limiting error of measurement is

$$\Delta_{lim} = \Delta p \sqrt{2}.$$

The error in measuring linearity characterized by a complex formula (for instance, a double curvature consisting of concave and convex curves) is determined by half the sum of the errors of maximum linear characteristics with opposite signs [5]. Let us assume that h_1 is the difference between ordinates in the convex section and h_2 is the difference between ordinates in the concave section. Then

$$\Delta h_1 = 2\left(m_1 - 2t_1\frac{m_1+k_1}{n}\right)\Delta p. \tag{10}$$

$$\Delta h_2 = 2\left(m_2 - 2t_2\frac{m_2+k_2}{n}\right)\Delta p,$$

$$\Delta_{max} = \frac{\Delta h_1}{2} + \frac{\Delta h_2}{2};\ \Delta_{lim} = \Delta p\sqrt{k_1+k_2}. \tag{11}$$

where k_1 and k_2 are the coefficients of Δp.

Let us take, for instance, a plate 10 m long with a double curvature (Fig. 3) and l = 250 mm, n = 40. Assuming that t_1 = 10; m_1 = 6; k_1 = 2; t_2 = 10; m_2 = 3; and k_2 = 1 (the cross section number of t_1 and t_2 is calculated within the limits of a curvature of the same sign), we obtain

$$\Delta_{lim} = \Delta p\sqrt{m_1+m_2-2t_1\frac{m_1+k_1}{n}-2t_2\frac{m_2+k_2}{n}} = \Delta p\sqrt{3}.$$

However, if m_1 = 10, k_1 = 0, m_2 = 10 and k_2 = 0, we have $\Delta_{lim} = \Delta p\sqrt{10}$.

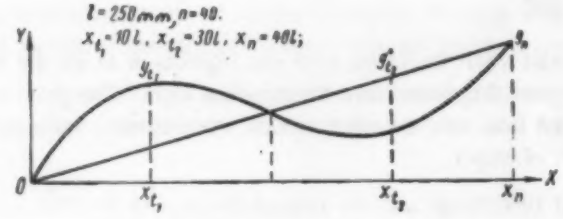

Fig. 3.

It is, therefore, most probable that the limiting error of the step-by-step method of measuring linearity of large plates and guide-rails (with a number of steps of the order of 20-40) will vary in the range of 1.5 Δp to 2 Δp, and only in the most unfavorable cases will reach the value of

$$\Delta_{lim} = \Delta p\frac{\sqrt{n}}{2}.$$

Checking the linearity and flatness of large plates and guide-rails by means of methods not based on the step-by-step principle is characterized by a completely different formation of errors.

a) The method of measuring gaps between the controlled surface and a straight line (or plane) taken as a reference and formed by a plate, straightedge, or an optical axis of the instrument. The sagging of the sample on its supports is not normally taken into account (the measuring arrangement is shown in Fig. 4).

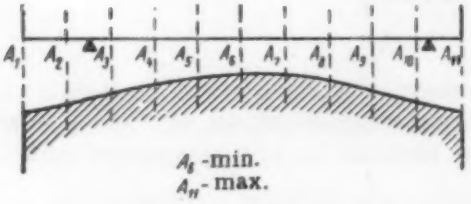

Fig. 4.

Here the non-linearity is considered to be half the difference between the maximum and minimum gap, i.e.,

$$h_{max} = \frac{A_{max} - A_{min}}{2}. \tag{12}$$

In determining the measuring method error, it should be considered that the errors in measuring each gap including the largest and the smallest of them are equal in their absolute value (the maximum permissible or standard error), and can only vary in their sign. Then the error of the above method of measurement is $\Delta_{lim} = \pm\Delta A$, where ΔA is the single error.

b) A method of using a telescope for sighting a mark displaced along the controlled line. The position of the telescope is adjusted by means of sighting the mark placed in the two extreme positions (at the extreme cross sections).

In this case nonlinearity is represented by half the difference between the readings at points which have the largest deviations (with opposite signs) from the datum line. The error in setting the telescope with respect to the reference points does not affect the error of measurement, since the datum line consists of the telescope axis. The error in this method like the one in the preceding method does not exceed a single telescope reading error.

c) The method of a taut string does not differ essentially from the method of gaps, since in it distances are measured from the controlled surface to the string. The value of a single error depends on the microscope used, and the measuring method error does not exceed a single reading error.

d) Hydrostatic methods do not differ in the nature of their resulting error formation from the above methods. The straight line connecting the extreme points of the controlled surface line is taken as the datum line. The measurement error does not exceed a single reading error.

e) Checking by means of Linnik's interferometer is based on measuring the total and local interference fringe curvatures observed in the instrument [1]. The measurement error of this method is determined by the error of estimating the curvature of fringes, i.e., it does not exceed in this case the error of a single measurement.

It will be seen from the above analysis that in the methods used for checking linearity and flatness of large plates and guide-rails based on the comparison of the controlled object with a sample, the individual measurement errors do not accumulate. However, when optical instruments are used the magnification of the controlled object considerably raises the effect of light refraction (due to air currents) on the value of the error. This effect increases both the single reading error and the error of the measuring method.

The processing of data obtained in these linearity and flatness measurements must be made by means of tables instead of graphical methods. Graphs should only be used to illustrate the general process. Graphs are also required in order to find the so-called twists in the surface [4, 5]. In this case, however, the value of deviations is still obtained from a table, and the graph only provides a better idea of the "twists" in the surface.

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PROFILOGRAPHING THE WAVINESS OF BALL-BEARING RACEWAYS

V. É. Vainshtein, Z. P. Grozinskaya, and A. G. D'yakova

Translated from Izmeritel'naya Tekhnika, No. 2,
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The work carried out by the Mechanical Engineering Research Institute of the USSR Academy of Sciences, with the object of standardizing surface waviness, and that carried out by the TsKBPP (Central Design Office for Bearing Production) for the purpose of establishing a production specification "Ball bearing raceway waviness. Technical conditions", have revealed the desirability of specifying optimum magnification in checking the waviness of revolving surfaces.

One of the differences between waviness and roughness consists in the difference of the spacing of irregularities.

Roughness and waviness have a marked effect on the operational properties of machine components. In the absence of waviness the height and shape of surface irregularities of the component determine its wear, friction factor and life. In the presence of waviness the spacing of irregularities becomes especially important, since its value determines the noise level in a rotating bearing.

Experimental work in determining the waviness of anti-friction bearing races was done by means of instruments Kalibr-VÉI and MIFI-2, which were equipped with additional devices.

Over 2000 surface measurements of races were made. Irregularities with a spacing to height ratio in the range of 300 to 14,000 were classified as waviness, whereas irregularities with a ratio not exceeding 300 were classified as roughness. The ratio of the spacing to the height of waves determines the choice of the horizontal and vertical magnification aimed at obtaining an accurate determination of both parameters from the profilogram.

The characteristic shape of waviness profilograms (wavograms) depends on the choice of the vertical and horizontal magnifications. Waviness profilograms of ball-bearing inner-race track surfaces were recorded for the same vertical and different horizontal magnifications. Owing to the different compression factors (the ratio of the vertical to the horizontal magnification) a comparison of profilograms becomes difficult. An incorrect selection of the scale ratios may lead to a faulty determination of the wave spacing. Fig. 1 shows a recording of an inner-race track waviness of ball-bearing type 306 after final grinding. The upper profilogram was recorded with a vertical

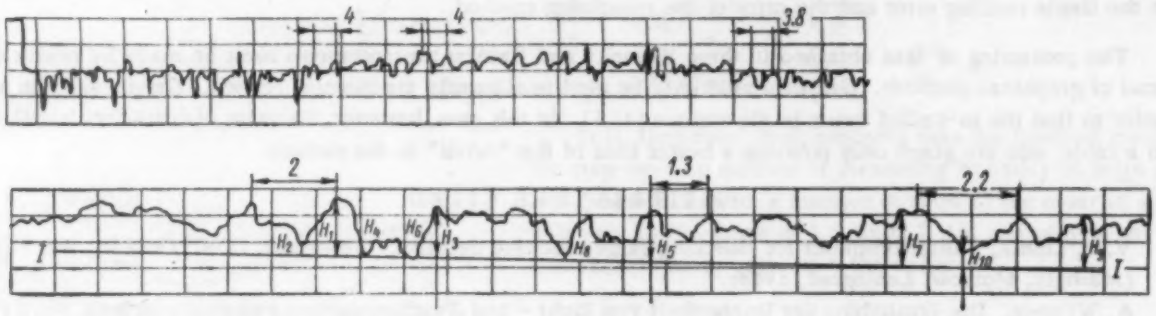

Fig. 1.

magnification of 2000 and a horizontal one of 1.6. This profilogram shows with sufficient clarity groups of irregularities with a spacing of 3.8-4 mm. A profilogram recorded from the same race with a magnification of $V_v = 4000$ and $V_h = 9.5$ (the lower curve) made it possible to discover other groups of irregularities with a spacing of 1.3-2 mm. The results thus obtained differ by a factor of about 2-3. This can be explained by the fact that with a small magnification a part of the irregularities which represent waves of a small height cannot be observed.

The measurement of surface waviness after polishing and grinding (the range of the checked race diameters was 10 to 40 mm) made it possible to find a mean value for the height and spacing of the waves (see table).

Type of finish	Grade of surface finish	Waviness parameters		Ratio of λ/H_W
		wave height H_W, μ	wave spacing λ, mm	
Grinding	8	1.5-5.0	1.0-4.5	300-1600
Polishing	10	0.25-1.5	2.0-6.5	2500-14,000

In a manner similar to that used for determining irregularities R_z according to GOST 2789-59 (All-Union State Standard), the height of the waves in this instance was determined from measurements made at 10 points as a mean distance between five of the highest and five of the lowest points of the waves within a measured segment of a determined length. This mean distance was taken from a line parallel to the direction of the waviness profilogram. The length of the measured segment was equal to half the race circumference.

Figure 1 shows a profilogram (the lower curve) of the inner-race track surface of ball-bearing type 306. The ordinates marked as H_1, H_3, H_5, H_7 and H_9 correspond to the five peaks and ordinates H_2, H_4, H_6, H_8 and H_{10} correspond to the five dips. Reference line I – I was drawn approximately parallel to the direction of the waviness profilogram.

For the convenience of processing profilograms it is advisable to choose a vertical magnification which would provide a height of irregularities on the profilogram in the range of 8-25 mm. Such values will be obtained when the waviness of ground races is recorded with a magnification of 4000-8000, and for polished races with a magnification of 15,000-20,000. Fig. 2 shows waviness profilograms obtained with the above recommended vertical magnifications.

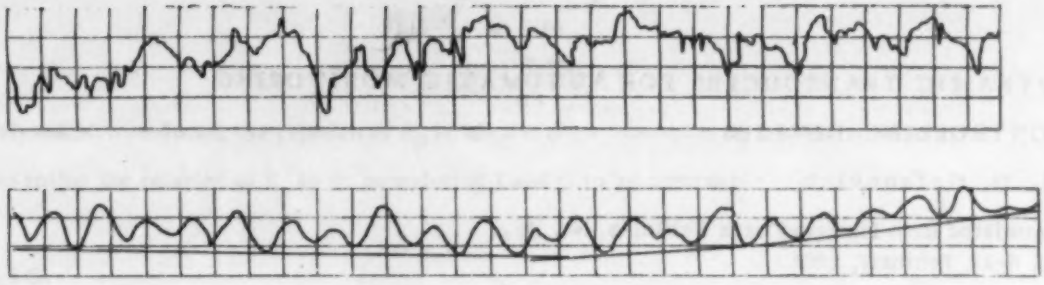

Fig. 2.

An insufficiently high vertical magnification becomes especially apparent when high grade surfaces are measured (grade 10-12), which have wave heights in the range of 0.1-0.8 μ.

The correct choice of horizontal magnification is of equal importance. In recording the waviness of polished and ground surfaces it is possible to recommend a horizontal magnification of 6 to 10 diameters. It should also be borne in mind that for polished surfaces it is possible to reduce the above magnification by a factor of 2, since the spacing of irregularities on polished surfaces is always larger than on ground ones. By using the recommended vertical and horizontal magnifications it is possible to establish an optimum compression factor: for polished surfaces of 1500-3000 and for ground surfaces of 400-1000.

At present commercial models of instruments for measuring waviness have not yet been produced; measurements are therefore made with instruments intended for measuring surface roughness.

Owing to the use of additional adjusting and fixing devices, a considerable length of the measured segments and irregular profiles, the measurement error in determining waviness is increased. In order to decrease the total error it is possible to reduce to a minimum the operators' errors which are inevitable in processing the profilograms. In such a case a selection of optimum magnification scales may play a decisive part. Thus, when five different operators processed the profilogram shown in Fig. 1 (the lower curve), the difference in evaluating the height of the waves amounted to 10% (V_v = 4000, V_h = 9.5), while with the other profilogram of Fig. 1 (upper curve, V_v = 2000, V_h = 1.6), the error rose to 50%.

In addition to ordinary production surfaces, waviness was also measured on surfaces with a regular waviness obtained by artificial means.

The evaluation of surfaces with regular and irregular waviness shows that in the latter case the choice of a correct magnification has a greater effect than in the former case. This conclusion is confirmed by processing profilograms obtained with different compression factors. Surfaces with a regular waviness provide more stable results. Test results have shown that the extension of measurements to a segment exceeding half the circumference makes very little difference to the measured heights of waves.

Reliable measurements are obtained if the controlled segment has a definite length and is continuous.

If the shape of the measured surface varies, the measured segment should consist of a continuous broken line composed of several sections each of which should be parallel to the waviness profilogram direction. This condition controls the accuracy in determining the wave spacing, which is an important parameter in evaluating the nature of the surface profile.

FERRODYNAMIC TRANSDUCERS FOR AUTOMATIC MONITORING AND CONTROLLING DEVICES

M. D. Gafanovich

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The compensation method is the most rational for transmitting readings of primary instruments in systems of automatic monitoring and control. Telemetering ac compensation systems are now being widely used. These systems include the one using rheostat transducers. Although relatively simple the above system has certain essential defects, the most important of which consists of unreliable contacts.

The present tendency in Soviet and foreign instruments and regulators is to discard rheostat transducers and change over to contactless converters,which provide highly reliable automatic devices.

The most widely used telemetering system employs differentially wound transformer transducers and provides reliable operation as a transmission link between the instruments and the regulators. The considerable nonlinearity of differential transformer transducers prevents, however, their use in computing circuits, thus limiting the sphere of their applications. The differential transformer transducers have also other less important defects, such as the effect of the plunger's position on the output voltage phase, and the difficulty in providing a linear kinematic connection between the transducer plunger, with its reciprocating movement, and the rotating components of the instrument.

The Khar'kov KIP (Control and Measuring Instruments) plant has developed a contactless ferrodynamic transducer which converts the angle of rotation into an appropriate voltage. On the basis of this transducer a new improved telemetering system has been designed and several computing circuits developed.

The principle of operation of the ferrodynamic transducer consists of the following. Coil 6 (Fig. 1), whose ends are connected to terminals 3 and 4 of terminal strip 7, can rotate about its axis in a radial magnetic field formed between the concentric surfaces of components 4 and 5 of the magnetic circuit. The magnetic flux is provided by an alternating current flowing through excitation winding 10 of coil 8, fitted over components 2 and 3 of the magnetic circuit. The ends of the excitation winding are connected to terminals 1 and 2 of terminal strip 7.

When the coil is in a neutral position (horizontal line through center 5), the emf induced in it is equal to zero, since the total number of the lines of force crossing the plane of the coil is equal to zero.

When the coil is rotated away from the neutral position through angle α the emf E_p induced in it is equal to[1]

$$E_p = \frac{\omega}{\sqrt{2}}\psi = \frac{\omega}{\sqrt{2}} B_m l R_m \alpha, \qquad (1)$$

where ω is ac angular frequency, ψ is the number of inter-linkages in the coil, B_m is the amplitude of the mean magnetic induction in the air gap, R_m is the mean radius of the coil, $l = 2Bw_p$ is the length of the coil conductor cut by the magnetic field, $\underline{b}$ is the width of the core, w_p is the number of turns in the coil.

The induction in the air gap may be represented as

$$B_m = \frac{\sqrt{2}\, I w_1 G}{\sigma R_c \Theta b}, \qquad (2)$$

where I is the excitation current, w_1 is the number of turns in the excitation winding, G is the permeance, σ is the leakage coefficient, Θ is the angle of the concentric part of the core.

Inserting the value of B_m from (2) into (1) we obtain

$$E_p = 2\frac{\omega w_p w_1}{\sigma\Theta} G I \alpha. \qquad (3)$$

or taking into account that for an actual transducer the values of w_p, w_1, σ and Θ are constant, we have

$$E_p = k_1 G I \alpha, \tag{4}$$

where

$$k_1 = 2 \frac{\omega w_p w_1}{\sigma \Theta}.$$

In ferrodynamic transducers the relation of E_p to all the three quantities α, I and G is used.

Let us examine the relation of E_p to α, considering I and G to be constant:

$$E_p = k_2 \alpha, \tag{5}$$

where $k_2 = k_1 I G$.

Figure 2A provides a graphic representation (curve 1) of this relationship, from which it follows that E_p varies between $-E_{p\,max}$ for $\alpha = -20°$ to $+E_{p\,max}$ for $\alpha = +20°$. For $\alpha = 0$, $E_p = 0$.

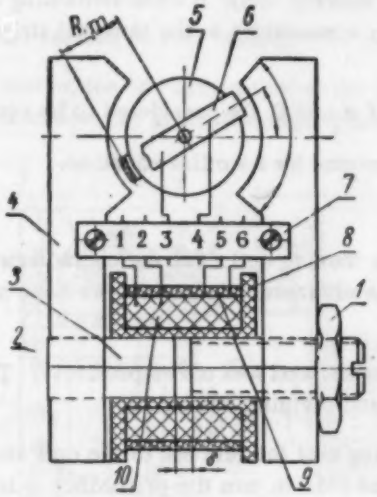

Fig. 1.

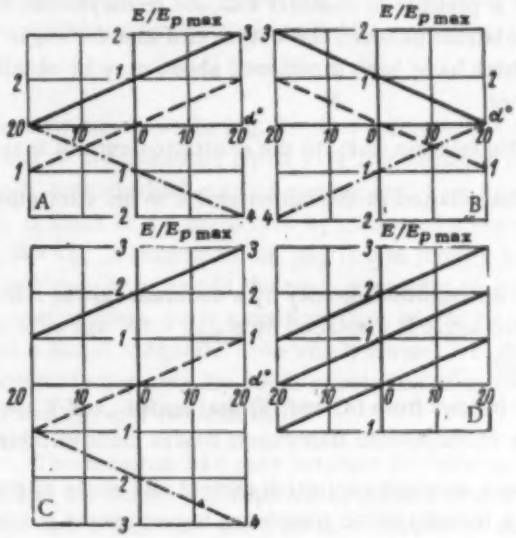

Fig. 2.

The signs "+" and "–" denote conventionally emfs E_p whose phases differ by 180° and whose angles α are calculated respectively clockwise and counterclockwise from the neutral position (see Fig. 1).

If the external circuit conductors connected to terminals 3 and 4 are interchanged, the graph shown in Fig. 2B is obtained.

The output emf E is measured in terms of the value of emf $E_{p\,max}$ obtained when the coil is rotated through 20° (the effective angle of rotation of the coil amounts to ± 20° from the neutral position). This method of expressing E provides a graph of $E = f(\alpha)$ independent over a wide range of the absolute values of I and G.

In several practical instances (mainly when carrying out computing operations) it is necessary to make the zero value of the emf correspond to one of the extreme positions of the coil instead of the middle position. This is attained by connecting in series with the moving coil a biasing coil 9—see Fig. 1 (wound over the excitation winding)—whose emf E_b, which is made to equal $E_{p\,max}$, does not depend on the rotation angle of the moving coil (see curve 2, Fig. 2A). At the same time E_b is related to I and G in the same manner as E_p. Thus, for any given value of α, variations of G and I within certain limits do not produce changes in the ratio of E_p/E_b. The ends of winding 9 (see Fig. 1) are connected to terminals 5 and 6 of terminal strip 7.

Curve 3 (Fig. 2A) of the total emf $E = E_p + E_b$ equal to the geometric sum of curves 1 and 2 will be obtained if E is taken from terminals 3 and 6 (see Fig. 1) and terminals 4 and 5 are short-circuited. If the conductors of the external circuit connected to terminals 3 and 6 are interchanged, curve 4 is obtained (Fig. 2A).

The normal convention is to assume that a ferrodynamic transducer possesses a right-hand turn if a clockwise rotation of the moving coil increases the absolute value of the output emf. In a left-hand transducer the output emf increases when the moving coil is rotated counterclockwise. According to the way in which the moving coil is connected the same transducer may possess a left-hand or right-hand turn. Thus, curves 3 and 4 (Fig. 2A) are characteristic for a right-hand rotation, similar curves (3 and 4 , Fig. 2B) represent a left-hand rotation and can be obtained if E is taken off terminals 4 and 6 (see Fig. 1) and terminals 3 and 5 are shortcircuited.

In certain cases (for instance, in controlling the relation between the fuel and air), it is necessary to make E change by a factor of 3 when the moving coil is rotated through the whole effective angle (see curve 3, Fig. 2C). This can be attained if the value of E_b (curve 2, Fig. 2C) is made equal to 2 $E_{p\ max}$, by increasing appropriately the number of turns w_b of the biasing winding 9 (Fig. 1).

The "direction of rotation" of a moving coil of a ferrodynamic transducer is determined in all cases by the position of the short circuit (between terminals 4, 5 for a right-hand and 3, 5 for a left-hand rotation) and the order in which external conductors are connected to the terminals (terminals 3, 6, and 4, 6 respectively).

It is possible to consider that the ferrodynamic transducers possess three (a, b, and c—Fig. 2D) basic characteristics (relations between the output emf and the angle of rotation of the moving coil). All the remaining characteristics which have been mentioned above may be obtained by appropriate connections at the terminal strip of the transducer.

The relation of E_p to the excitation current is represented by (4) if α and G are considered to be constant.

The relation of the output emf E to the excitation current is represented by a similar equation:

$$E = k_1 GI\alpha'. \tag{6}$$

It differs from (4) only by a different initial reference angle of the moving coil. For the characteristic curve b the zero angle is displaced by $\alpha_{max} = 20°$ and $\alpha' = \alpha + \alpha_{max}$. For the characteristic curve c we have $\alpha' = \alpha + 2\alpha_{max}$.

It follows from (4) and (6) that emfs E_p and E are proportional to products αI and $\alpha' I$ respectively. This property of the ferrodynamic transducers makes them suitable for multiplying and dividing operations.

For a constant excitation current and angle of rotation of the moving coil the relation of the coil and output emfs of a ferromagnetic transducer to permeance is represented by (4) and (6). In turn the permeance G is a function of the airgap δ (Fig. 1) between components 2 and 3 of the transducer core.

Component 3 is fixed rigidly in detail 4 of the core and is known as the fixed plunger. The moving plunger 2 has a thread and can be fixed in any required position by means of lock-nut 1. Thus, the required airgap δ can be fixed by screwing or unscrewing the adjustable plunger.

By varying airgap δ it is possible to vary for a constant excitation current the slope of the basic transducer characteristic, rotating it round the point which corresponds to a zero emf. This property of the transducer makes it possible to match the characteristics of two or more transducers working in the same circuit.

Ferrodynamic transducers are produced in 6 versions (see table).

Transducer type	Nominal supply voltage, v	Nominal excitation current for $\delta = 0$, ma	Type of characteristic	No. of turns in excitation winding	No. of turns in the displacement winding	Displacement winding emf for a nominal excitation current and $\delta = 0$, v
DF 1	60	50	a	3500	-	-
DF 2	12	250	a	680	-	-
DF 3	60	50	a, b	3500	75	1.2
DF 4	12	250	a, b	680	75	1.2
DF 5	60	50	a, c	3500	150	2.4
DF 6	12	250	a, c	680	150	2.4

Note: The type a characteristic is obtained in the last four types if the output emf is tapped directly off the moving coil without passing through the biasing winding.

Below we give the ferrodynamic transducer characteristics common to all the types and obtained at the factory in preliminary testing.

The moving coil emf for a normal excitation current, a fully screwed-in adjustable plunger, and a moving coil displaced from its neutral position through 20° amounts approximately to 1.2 v.

The nonlinearity in the relation between the emf and the moving coil deflection angle does not exceed 0.4%.

The nonlinearity in the relation between the transducer emf and the excitation current does not exceed 0.5%.

The range in the variation of the transducer basic characteristic slope for a displacement of 1.5 turns of the adjustable plunger and a constant excitation current amounts to approximately 40%.

The effective rotation angle of the moving coil is 40° (±20°).

The angle of rotation of the moving coil from stop to stop is 60°.

The moment of the spiral springs which press the moving coil against its stop is not less than 3.5 kg-wt · cm. When the moving coil is turned to its end stop the moment of the spiral springs increases to 6-10 kg-wt · cm.

The coil consists of 1200 turns of 0.06 mm PEV1 wire.

The construction and dimensions of the ferrodynamic transducer are shown in Fig. 3. The core consists of two blocks 15 interconnected by nonmagnetic plates 14 which are fixed to the blocks by rivets 11. The central cylindrical core 8, around which rotates moving coil 5 on agate bearings, is fixed to the main core by means of a nonmagnetic bracket 16. A concentric air gap is thus formed between the cylindrical boring in the main magnetic circuit and the central core. Such a configuration of the air gap provides a radial magnetic field which ensures a highly linear relationship between the angle of rotation of the moving coil and the emf induced in it.

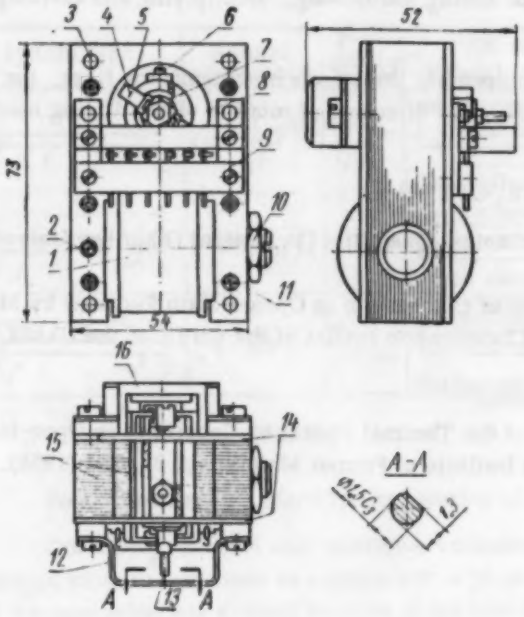

Fig. 3.

The required free play between the moving coil pivots and the bearings is adjusted by means of screw 6 secured with a locknut. For a correct adjustment the coil should have a slight radial but no axial play.

In order to avoid any play between the gear fitted over the moving coil axle 13 and the driving gear connected through the instrument mechanism to the transducer, the moving coil is supplied with two taut spiral springs. These springs also serve as conductors to connect the coil to the external circuit; one of the springs 7 can be seen in Fig. 3.

The effective rotation angle of the moving coil (40°) is marked by a graduation 4 on the front plate 14 and the moving coil former 5. In order to protect the moving coil from accidental damage the transducer is supplied with bracket 12.

Coil 1 with its excitation and biasing windings is mounted over the fixed and adjustable plungers in the lower part of the transducer between the two blocks 15 of the main core. The fixed plunger is secured by means of setscrew 2. The adjustable plunger is secured in the required position by means of locknut 10. The lead-out conductors of the excitation, moving and displacement coils are connected to the terminals at the top of terminal strip 9.

The transducer is mounted by means of its four holes 3. In order to avoid the effect of external magnetic fields the transducer is placed in a steel screen 1 mm thick.

Ferrodynamic transducers are successfully used for remote transmission of readings, remote control of regulators, algebraic addition of several quantities, as well as the division and multiplication of two quantities [2, 3].

On the basis of these ferrodynamic transducers the Khar'kov KIP plant [4] has developed an equipment which provides automatic monitoring and control of various thermo-technical parameters. A prolonged use of this equipment in an operating metallurgical plant showed a very high reliability of the ferrodynamic transducers as well as of the instruments and regulators with which they operate.

Conclusions. The ferrodynamic transducers compare favorably with differential transformer transducers:

1) by their better linear relationship between the output emf and the angle of rotation (displacement) of the coil, which makes it possible to correct the zero of the indicating instrument without an additional transducer and without introducing any additional errors;

2) by the possibility of changing continuously and without using any contacts (by means of the adjustable plunger), and over a wide range, the transducer transformation ratio (the slope of the characteristic), by means of simple adjustments;

3) by the possibility of obtaining characteristic curves with a parallel displacement with respect to each other;

4) by the small moment required for rotating the moving coil and the absence of a moment of reaction in it;

5) by the stability of the output voltage phase in the effective angle range of the moving coil;

6) by the simple linear kinematic coupling between the transducer coil and the rotating elements of the instrument;

7) by the possibility of using ferrodynamic transducers for adding, subtracting, multiplying and dividing circuits without any rewiring or the use of matching dividers;

8) by the fact that ferrodynamic transducers can fully compensate the effects of transmission lines; the easy setting of a transducer for a left-hand or right-hand rotation makes the direction of rotation of the driving mechanism immaterial.

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DIAPHRAGM VIBRATOR TEST RACK

A. P. Pleshko and V. V. Perfil'ev

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Until recently the main obstacle to the wide application of vibration transducers and accelerometers in studying complex mechanico-hydraulic systems under vibration conditions consisted of the lack of a reliable method for testing the transducers' frequency characteristics, for their dynamic calibration, and for determining their sensitivity to side (transverse to the transducer axis) vibrations. The existing vibration test racks provide vibration accelerations not exceeding 30-60 g at frequencies up to 300 cps and only of a few g at frequencies of 2000-3000 cps. Vibration test stands of the tuning-fork type provide vibration accelerations of some 800 g at fixed frequencies in the range of 200-1500 cps.

A further extension of the range of such racks cannot be considered advisable, since for higher frequencies the height h of the tuning fork arm becomes comparable to its length l. For instance, a tuning fork arm 100 mm long has at 1500 cps a height of 25 mm, for the same length and a tuned frequency of 3 kc its height amounts to 50 mm, and for a frequency of 4.5 kc to 75 mm. It should be noted that for tuning-fork lengths less than 100 mm its oscillating amplitude becomes extremely small, and it becomes increasingly affected by the place of measurement, since the angular displacement of each end has an increasing effect on the oscillations. An attempt to use a tuning fork 65 mm long tuned to 3 kc was only partially successful: the maximum oscillation amplitude with unloaded arms amounted only to 15-20 μ, which provided an amplitude of vibration accelerations of 600-720 g. Thus, it should be considered that the maximum amplitude obtainable by a tuning-fork vibrator is found at a frequency of 1500 cps.

A theoretical investigation of the possibility of making vibrators for higher frequencies shows that it is necessary to use for this purpose a tuned, balanced mechanical oscillating system of a diaphragm type. This investigation was reduced to finding the natural frequency (first harmonic) of three different mechanical systems, with the parameters determining the frequency being selected the same for the three systems.

The following types of mechanical oscillating systems were considered: a beam with a fixed end (cantilever, tuning-fork vibrator), a beam with two fixed ends (frame vibrator), a round plate with fixed edges (diaphragm vibrator).

The schematics of these systems, formulas for determining their natural frequencies and the ratio of the natural frequency of each system to that of the cantilever beam are given in Fig. 1. From this data it will be seen that in order to obtain large vibration amplitudes at high frequencies it is necessary to use diaphragm type vibrators.

The type of construction we adopted for a diaphragm vibrator is shown in Fig. 2.

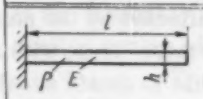
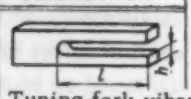
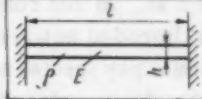
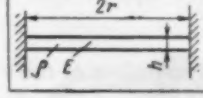
System type	Natural frequency	Frequency ratio	Type of construction
	$f_1 = 0.04 \frac{h}{(\frac{l}{2})^2}\sqrt{\frac{E}{\rho}}$	$\frac{f_1}{f_1} = 1$	 Tuning-fork vibrator
	$f_2 = 0.258 \frac{h}{(\frac{l}{2})^2}\sqrt{\frac{E}{\rho}}$	$\frac{f_2}{f_1} = 6.3$	Frame vibrator
	$f_3 = 0.5 \frac{h}{r^2}\sqrt{\frac{E}{\rho}}$	$\frac{f_3}{f_1} = 12.2$	Diaphragm vibrator

Fig. 1.

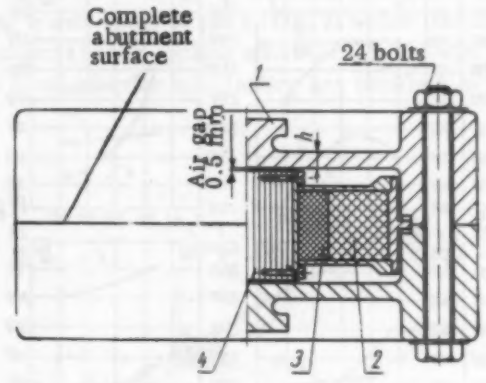


Fig. 2. 1) Vibrator table; 2) dc coil; 3) ac coil; 4) dust core.

Four vibrators were made for frequencies of 2, 3, 4, and 5 kc.

Contrary to a frame and cantilever vibrators with electromagnetic excitation, the excitation system of a diaphragm vibrator was made in a single unit with the core, and suspended in such a manner that the natural frequency of the suspension was a small fraction of the operating vibration frequency.

Another essential difference of diaphragm vibrators consists in the use of four separate damping feet for each vibrator, thus making it possible to stand the vibrator on an ordinary table.

During the assembly and adjustment testing of finished vibrators the following work was carried out:

1. The natural frequency of each half of the diaphragm casing was measured and adjusted to be equal to the other half by varying the thickness h of one of the diaphragms. Oscillations over a wide frequency range were established by means of the electromagnetic system of ordinary headphones and an audio-frequency oscillator type ZG-2A. The maximum amplitude of the diaphragm oscillations corresponded to its resonance and was determined by means of a piezoelectric probe and a cathode-ray oscilloscope.

2. The conditions of joining and securing the two halves of the vibrator casing along a line of perfect abutment (see Fig. 2) were determined in order to obtain a maximum Q-factor for the system. For this purpose the degree of compression by means of nuts was varied and packing of various thicknesses was inserted. The maximum Q-factor was

obtained when two 0.08 mm tin gaskets were used. It is also advantageous to raise the number of fastening bolts round the vibrator casing.

3. The optimum working conditions were selected for the magnetization and audio-frequency coils. The magnetization coil has 600 turns of 1.5 mm type PÉV wire; the variation of the current flowing through it by means of a series-adjustable resistor changed very little (by worsening) the vibrator operation. The audio-frequency coil consists of 3 single-layer sections of 28 turns each made with 1.5 mm type PÉV wire for vibrators of 2 and 3 kc and of 2 such sections for vibrators of 4 and 5 kc.

On the basis of the results thus obtained and in order to provide better cooling all the vibrator coils were extended by two series-connected audio-frequency sections. It was also established that with such an arrangement the excitation system does not require any forced cooling.

4. The external load characteristics of finished vibrators were determined in terms of the relation of amplitude 2A, the vibration acceleration a and frequency f to the vibrator load. Tests were carried out for 3 loads of 50, 100 and 200 g (Fig. 3).

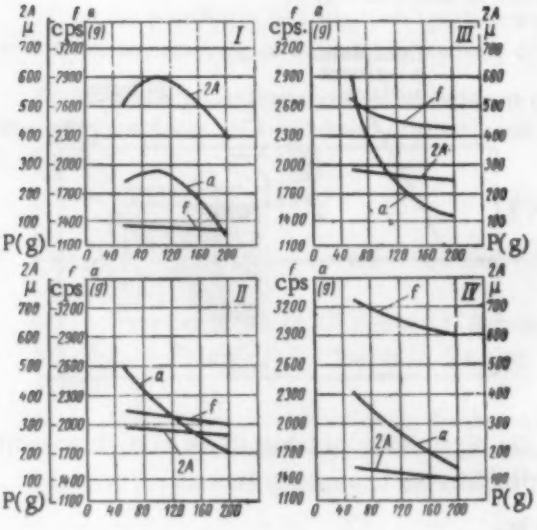


Fig. 3. External characteristic curves of diaphragm vibrators. a) Acceleration curves; f) frequency curves; 2A) amplitude curves. I) curves for a vibrator with a nominal f = 2000 cps; II) same for f = 3000 cps; III) same for f = 4000 cps; IV) same for f = 5000 cps.

When the load was made up of a strain-gauge type vibration transducer, whose connecting leads greatly lowered the Q-factor of the whole system, the amplitude of oscillation and the corresponding vibration acceleration dropped by 30-50%.

It should also be noted that the vibrator Q-factor and hence its oscillation amplitude are noticeably affected by the presence of any insecurely fastened or vibrating details. Thus, with a poorly tightened up transducer it was impossible to obtain accelerations exceeding 600 g at a frequency of 3.5 kc. In this connection the designers of vibration transducers intended to work at high frequencies and large amplitudes should pay special attention to the fixing of these transducers to the object under test, by providing their best possible adhesion.

In addition to the above work, the two halves of the vibrator were made to operate symmetrically. For this purpose the vibrations of both sides of the diaphragm vibrator were measured simultaneously. Measurement results show that the difference in the amplitude of vibrations of the two halves of the casing does not exceed the measurement error obtained by microscope type OMS-3. The inspection of the oscillogram obtained in testing the vibrator at 2.3 kc and its comparison with the shape of a calculated sine-wave show that the oscillations thus obtained are sinusoidal.

It should be remembered that the work of the above vibrators is related to powerful audio oscillations in the range of 1.5-5.0 kc, i.e., precisely in the range of frequencies which are most irritable to the human ear. The intensity of oscillations is so high that it seems to exceed considerably the permissible level and reaches the threshold of a painful sensation. The diaphragm vibrators should, therefore, be used in special premises with sound-absorbing walls.

Conclusions. The above diaphragm-type vibrators provide sinusoidal vibrations at an amplitude a of ~ 2000-3000 g at four fixed frequencies in the range of 1.5-4.0 kc, with a load not exceeding 100-200 g.

RECORDING DYNAMOMETER FOR MINING MACHINERY

V. K. Tyutyunnik and P. G. Glumakov

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 14-15, February, 1961

In studying the operation of combines and cutters under pit conditions it is important to be able to measure accurately the traction effort of their cables. These measurements are mostly made by means of dynamometers with a visual scale. Such a method provides only very approximate results, since the loading changes continuously and only the reading of its mean value is obtained.

The TsÉIIL of the Dongiprouglemash (the Central Experimental and Research Institute and Laboratory of the Donets State Institute for the Design and Planning of Coal Mining Machinery) has developed an explosion-proof spring dynamometer (Fig. 1) with a mechanically recording system and a clockwork tape-propelling mechanism with a centrifugal speed regulator. This dynamometer provides, owing to its low inertia and long-term uninterrupted operation, the possibility of measuring simultaneously the nature and the peak values of the loading, and investigating the effect produced on them by changing operating conditions.

The measuring device of the above dynamometer consists of two exchangeable measuring springs for the ranges of 0-3000 kg-wt and 0-8000 kg-wt. The moving bar of the spring is connected to pin 1 (Fig. 2) which transmits to lever 2 of the recording system the displacement-which is proportional to the applied effort-of this bar with respect to the stationary bar when the spring is being extended. The pin is tapered,thus eliminating any backlash in the recording device when the pin is displaced along its axis.

Fig. 1.

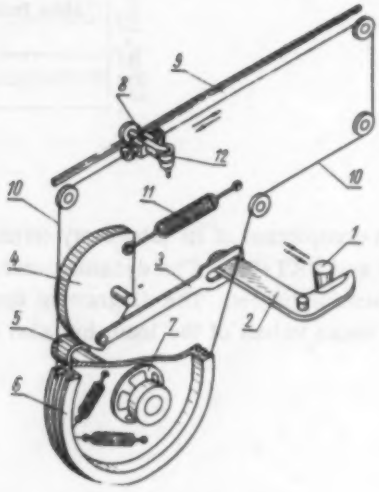


Fig. 2.

The lever turns by means of connecting rod 3 the geared sector 4 which engages with the geared wheel 5 fixed to the axle of drum 6. The drum is connected to the axle by means of a friction device 7, which protects the recording system from breakage if the dynamometer is overloaded. The forward movement of the recording carriage 8 along guide rack 9 is made by means of two cords 10 fixed to the drum. The drums are exchangeable for various measuring ranges.

The recording system is returned to its initial position under the action of spring 11. The readings are recorded by means of a carriage-mounted exchangeable pen 12 which writes on a chart perforated at both edges and 120 mm wide. The schematic of the chart-propelling mechanism is shown in Fig. 3. The chart is unrolled from the feeding reel through geared rollers 1 and a clockwork mechanism 2 with a centrifugal regulator 3 and manual winding 4. Its propulsion speed can be regulated continuously between 90 and 180 mm/min by a special device 5 which operates the centrifugal speed regulator. The starting and stopping of the chart-propelling mechanism are done by means of locator 6. The spring can be wound for a continuous operation of the mechanism during 15 minutes.

The recording device of the dynamometer and the tape-propelling mechanism are mounted on a common chassis placed in a welded casing. The spring-winding handle, the speed-control knob and the locator are mounted on the side wall of the casing. The casing lid is mounted on a swivel and has a window with a protection grid for observing the operation of the instrument. The lid fixes tightly onto the casing by means of packing in order to protect the instrument from coal dust or water.

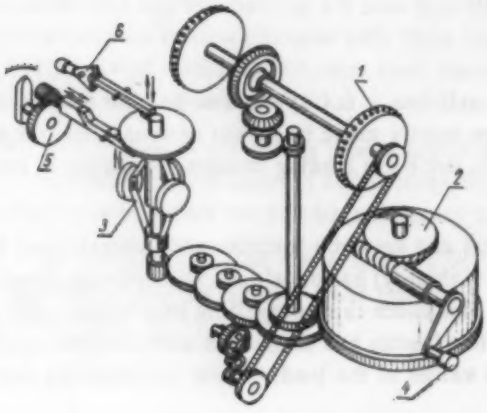


Fig. 3.

An experimental model of the above dynamometer was tested out in the laboratory under pit conditions. In order to determine the inertia of the recording system at a frequency of load variations in the range of the pulse frequencies in the drive of coal combines and cutters, tests of the recording system were carried out by means of a special eccentric device with a reduction gear which provided load variations at a repetition frequency of 59 to 122 oscillations per minute. The mean load and its amplitude remained constant. It was established that the recording system does not introduce any amplitude distortions at these frequencies.

The dynamometer complete with measuring spring was tested on a test rack which provided load oscillations at various frequencies but a constant amplitude registered by the dynamometer and recorded on the chart. For load oscillation frequencies between 33.5 and 95 oscillations per minute no amplitude distortions were observed.

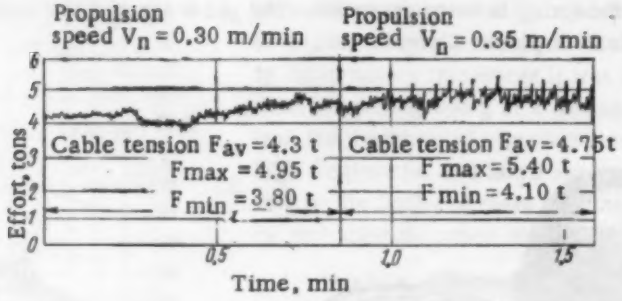


Fig. 4.

On completion of its laboratory testing the dynamometer was used in a mine for studying the operation of combines K8 and UKT-2m. The dynamometer, which was calibrated up to 6 tons, was connected through a block and tackle to the combine cables. The diagram of the tensions in the combine cables (Fig. 4) makes it possible to estimate not only the mean values of the load, but also its pattern and the peak values for different conditions of operation.

METHOD FOR MEASURING THE NATURAL FREQUENCIES OF BEARING RACES

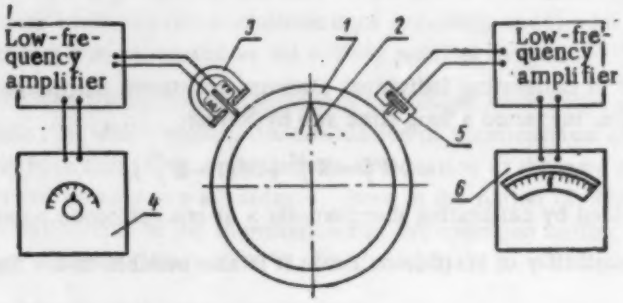
B. E. Bolotov

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 15-16, February, 1961

In studying the dynamic processes in machines subjected to heavy vibrations it is necessary to know the natural frequencies of their components in order to prevent resonance effects. Thus, in analyzing the reasons for vibrations

and noise in ball bearings it was found that a considerable proportion of the general noise was provided by the ball race, which acted as a resonator (this applies particularly to the external ball race). The natural frequency of the external race determines the pitch of the tone, which may be called the natural tone of the bearing. The pitch of the natural tone is determined by the thickness of the race and its diameter and does not depend on the speed of rotation of the bearing.

The method we employed for measuring the natural frequency of the ball races is based on the well known resonance effect, i.e., the coincidence of the frequency of forced oscillations with the natural frequency of the ball race.



The block-schematic of the instrument is given in the figure attached. The tested ball race 1, suspended on fulcrum 2, is excited by the electromagnetic vibrator 3, which is fed from an audio-frequency oscillator 4. The piezoelectric transducer 5 registers the oscillations of the ball race and feeds an electrical signal to the amplifier, which after detection operates pointer instrument 6. The piezoelectric transducer can also be connected to a cathode-ray oscilloscope.

Measurement of the natural frequency of the ball race is carried out in the following manner: the ball race under test is suspended from the fulcrum, and the electromagnetic vibrator and piezoelectric transducer are clamped to it. By varying the excitation frequency and observing the maximum deflection on the indicating instrument the resonance frequency is determined.

METHODS FOR CALIBRATING AGAINST THE PRACTICAL TEMPERATURE SCALE IN THE REGION OF 10-90°K

D. I. Sharevskaya and P. G. Strelkov

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The simplest method of calibrating individual platinum resistance thermometer scales against a standard table is based on Matthieson's rule, suggested a long time ago by Nernst:

$$W_T^x = W_T^{st} + M(1 - W_T^{st}), \tag{1}$$

where M is a constant obtained by calibrating thermometer x at one reference point [1].

On the basis of the feasibility of Matthieson's rule it is also possible to use the reduction method by means of Z-functions:

$$Z(T) = \frac{W_T^{st} - W_{T_1}^{st}}{W_{T_2}^{st} - W_{T_1}^{st}} = \frac{W_T^x - W_{T_1}^x}{W_{T_2}^x - W_{T_1}^x}, \tag{2}$$

for which purpose, however, it is necessary to calibrate thermometer x at two reference points [2].

The accuracy obtained by either method is determined by the applicability of Matthieson's rule at temperatures below 90°K.

Tests of the relation between the resistance of platinum and temperature [3] showed that Matthieson's rule applies with an accuracy equivalent to 0.01° only down to 60-50°K. At lower temperatures considerable deviations from Matthieson's rule are observed, making the above simple calibration methods unsatisfactory.

TABLE 1

Grade	IKh-6-11		V		R-12		IKh-4		Am-I		R-54		Am-III		Am-II		R-50		IKh-3	
$\alpha = 0.0039$	251		250		247		242		228		215		209		206		205		178	
$\Delta T \cdot 10^3$ / T°K	By formula		By formula		By formula		By formula		By formula		By formula		By formula		By formula		By formula		By formula	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
20	60	0	90	0	280	0	40	0	400	0	10	0	327	0	260	0	40	0	10	0
22	30	17	80	2	170	5	18	10	270	8	30	22	213	20	160	22	31	28	33	28
24	20	14	60	4	140	12	7	16	215	12	40	32	170	24	115	34	20	32	40	32
26	10	12	50	7	120	15	2	21	180	16	45	40	135	27	84	42	30	46	40	33
28	5	19	40	8	90	20	5	21	140	14	43	41	127	29	57	46	30	47	35	31
30	2	18	30	9	70	20	8	21	110	18	41	39	100	26	40	48	30	47	30	28
35	2	18	20	10	46	23	9	20	80	19	47	35	70	27	20	48	30	40	20	20
40	4	16	10	13	30	25	9	18	60	20	31	30	46	27	5	48	25	33	17	15
45	4	14	7	13	20	23	8	15	40	20	24	23	30	27	0	42	20	27	10	10
50	4	12	5	12	13	23	6	12	25	20	18	18	20	25	3	40	14	21	7	6
54.36	4	11	4	10	10	20	4	10	25	20	15	15	15	23	2	32	17	5	5	5
60	4	8	2	9	6	20	3	7	17	20	13	10	10	21	1	25	9	12	4	3
70	3	6	2	5	4	12	2	5	10	15	7	6	5	16	0	16	4	7	3	3
80	2	1	1	3	2	6	0	2	4	8	3	3	8	8	2	6	2	3	2	2
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	1	1	2

Recently more complicated methods were suggested which aimed at attaining a sufficiently high accuracy (~ 0.01°) for calibrating individual thermometer scales against the standard one [4-8]. However, these methods are applicable to grades of platinum approaching the standard grade and only down to 20°K, whereas the practical limit of platinum thermometry is considerably lower (10-12°K).

In this work we apply the above methods to thermometers made of 10 different grades of platinum, which were investigated experimentally [3], and we also examine yet another calibration method applicable to temperatures below 20°K.

Application of Various Correction Methods to Thermometers Previously Investigated Experimentally [3]. By means of the simplest correction formulas (1) and (2) we calculated W^{x}_{T} from formula (1) and Z^{x}_{IKh-6} from formula (2) for all 10 thermometers in the range of 20-90°K. The results of comparing the calculated and experimental values in equivalent temperatures are shown in Table 1.

Temperatures down to which it is possible to use each of the above thermometers with an error not exceeding 0.01° are shown in the above table when the simplest corrections according to (1) with the use of one constant are applied, for which the thermometer was calibrated at the boiling point of oxygen.

The correction errors are given for each thermometer in the temperature range of 20-90°K when applying Z-functions according to formula (2), which require the calibration of thermometers at two points, the boiling points of oxygen and hydrogen. Let us note that (2) is equivalent to an equation of the type of formula (1) with two constants and, in our opinion, does not provide any advantages. Even in the region of nitrogen temperatures the application of the Z-function requires calibration of the thermometer at the hydrogen boiling point (in addition to the oxygen boiling point) and the range is limited down to 20°K.

Next we examined more complicated correction methods.

Having measured the resistance of six thermometers made of the same grade of platinum as the reference thermometer, Loss and Morrison [5] suggested a correction method for the region of 20-90°K which provides an accuracy of ~ 0.002° if the Z-function correction is used for the reference thermometer. The correction of the form $\Delta R = A \sin(BT + C)$ for resistance calculated by means of the Z-function is determined by the international temperature scale constants for a given thermometer. The application of this method to the platinum thermometer type IKh-4, which was investigated by us [3] and approached the standard grade platinum IKh-6, did not provide satisfactory results (Table 2, column 2).

TABLE 2

T°K	By the Loss and Morrison method $W^{IKh-4}_{exp} - W^{IKh-4}_{cal}$, ΔT	By the Schultz method $W^{IKh-4}_{exp} - W^{IKh-4}_{cal}$, ΔT	By the Van Dijk method $Z^{IKh-4}_{exp} - Z^{IKh-4}_{cal}$, ΔT	By the Van Dijk method with Z^{IKh-6}_{T} and Z^{IKh-3}_{T}, ΔT
1	2	3	4	5
24	0.019°	0.22°	0.14°	0.05°
30	0.021	0.07	0.14	0.035
40	0.016	0.017	0.08	0.015
60	0.006	0.005	0.02	0.001
80	0.002	0.005	0.04	0.002

It is obvious that the above method provides an error of ~ 0.002° only for thermometers made of platinum very close to the standard grade, does not extend below 20°K and requires calibration in addition to the hydrogen boiling point also at other points of the International Temperature Scale with a rather complicated calculation of the correction term.

The correction method suggested by Van Dijk [6] for a temperature range of 20-90°K amounts to obtaining a Z-function for the given thermometer by means of linear combinations of tabulated Z-functions of two known grades of platinum obtained by calibration against gas thermometers, and to the calibration of the given thermometer at the triple point of oxygen*, i.e., $Z = Z_I + \lambda\Delta$, where $\Delta = Z_{II} - Z_I$, and $\lambda = (Z_{(3)} - Z_{I(3)})/\Delta_{(3)}$. Subscript (3) denotes the values obtained at the triple point of oxygen.

The application of the above method to thermometer type IKh-4 provided unsatisfactory results (see Table 2, column 4). We used a variation of this method, having chosen for the functions of Z_I and Z_{II} two tables of far-removed grades of platinum obtained by the same calibration against a gas thermometer (grades IKh-6 and IKh-3). However, in this case we did not obtain a sufficiently accurate correction (see Table 2, column 5).

*Let us note that Hoge [4] was first to suggest the representation of relation R(T) of a given thermometer in the form of linear combinations of two known tabulated relations, $R_I(T)$ and $R_{II}(T)$.

Thus Van Dijk's method cannot be considered satisfactory, at least for the above grade of platinum, although it is close to the standard grade.

Schultz [7] bases his correction method on a perfectly correct assumption about the relationship of ρ and T described in the work of Kohler and Neckar [9]. However, a number of assumptions and simplifications which, in our opinion, were made unjustifiably by the author made us lose confidence in the correctness of this method. The data calculated by us from Schultz's main formula for a thermometer type IKh-4 differ considerably from experimental results (see Table 2, column 3).

TABLE 3

Grade	IKh-6-11	V	P-12	IKh-4	Am-I	R-51	Am-III	Am-II	R-50	IKh-3
α=0.0039	251	250	247	242	228	215	209	206	205	178
$\Delta Z_3 \cdot 10^4$	1.7	1.6	−3.4	1.5	3.2	2.3	3.7	5.1	2.7	0.7
T°K	$\Delta T \cdot 10^3$°									
12	70	100	530	200	130	700	165	240	700	—
14	40	50	200	80	70	300	50	120	300	530
16	20	20	60	30	30	120	10	50	100	200
18	2	5	12	10	10	20	5	13	40	60
20	1	2	1	2	2	3	10	0	3	3
22	5	0	3	0	0	18	10	10	22	25
24	6	2	2	2	2	22	8	12	20	30
26	10	2	2	2	2	26	9	17	33	30
28	9	0	0	1	1	29	7	17	32	27
30	8	0	1	1	1	25	6	16	28	24
35	7	2	1	1	1	21	5	15	22	16
40	4	3	2	1	1	15	4	13	15	10
45	3	2	1	1	1	8	3	10	9	5
50	1	1	1	1	1	4	2	6	4	1
54.36	0	0	0	0	0	0	0	0	0	0
60	1	0	0	1	1	4	0	4	3	0
70	1	2	3	0	0	5	1	7	6	0
80	6	2	3	0	0	4	2	6	5	0
90	0	0	0	0	0	0	0	3	1	2

The method suggested by Barber [8] consists of calculating for each thermometer the correction $\Delta Z = -\Delta Z_3 / 1221.3 (T^2 - 110.46T + 1828.4)$ for the Z-function, where ΔZ_3 is the difference between the experimental and tabulated values of the Z-function at the triple-point temperature of oxygen.

As a criterion of the applicability of this method, which provides an accuracy of $\sim 0.003°$, the author considers the condition that $\Delta Z_3 \leq 2 \cdot 10^{-4}$. The differences between the calculated and experimental values of the Z-function in terms of their temperature equivalents, as well as the values of ΔZ_3, are given in Table 3. Barber's method is completely satisfactory for several grades of platinum in the range of 20-90°K, but it is not satisfactory below 20°K. Barber's method requires additional calibration of thermometers at the triple point of oxygen by means of rather complicated apparatus and methods of measurement [10]. Moreover, it will be seen from Table 3 that the requirement that $\Delta Z_3 \leq 2 \cdot 10^{-4}$ does not constitute a requirement of the applicability of this method. It is obvious that a sufficient accuracy ($\sim 0.01°$) of scale correction by this method requires in any case the selection of platinum grades ($\alpha > 0.003923$).

The Suggested Correction Method. It has already been pointed out that the inaccuracy in correcting individual thermometer scales against the standard scale by means of simple equations (1) and (2) is due to the deviation of the relation between the platinum resistance and temperature from Matthieson's rule. The general theory of deviations from Matthieson's rule has been worked out [9], and we thought it advisable to examine the correction method based on the results thus obtained. According to [9] the resistance of a metal can be represented as

$$\rho(T) = \rho_{id}(T) + \rho_{res} + \Delta, \tag{3}$$

where $\rho_{id}(T)$ is the "ideal" metal resistance, which depends on temperature; ρ_{res} is the residual resistance, which does not depend on temperature and is due to impurities and distortions of the metal grid; and

$$\Delta = \eta\gamma \frac{\rho_{id}(T)\,\rho_{res}}{\eta\rho_{res} + \gamma\rho_{id}(T)} \tag{4}$$

is the resistance additional to that provided by Matthieson's rule and is due to the interaction between the "ideal" grid and its distortion, and is a function of ρ_{id} and ρ_{res} as well as a function of temperature; η and γ are positive constants.

We obtained from (3) and (4), by neglecting terms of the order of $\rho_{res}^2 / \rho_{0°C}$ or of higher orders, that

$$W_T = W_T^* + \sigma(1+\eta)(1-W_T^*) - \frac{\eta^2\sigma^2}{\eta\sigma + \gamma W_T^*}, \tag{5}$$

where

$$W_T = \frac{\rho(T)}{\rho_{0°C}}; \quad W_T^* = \frac{\rho_{id}(T)}{\rho_{id}(0°C)}; \quad \sigma = \frac{\rho_{res}}{\rho_{0°C}}.$$

In the limiting case, when $W_T^* \gg \sigma$, i.e., at sufficiently high temperatures, (5) becomes

$$W_T = W_T^* + \sigma(1+\eta)(1-W_T^*). \tag{6}$$

Relation (6) is similar to relation (1), so here $M = \sigma(1+\eta)$. This should be expected, since at temperatures higher than 50-60°K Matthieson's rule applies with sufficient accuracy.

In the other limiting case, when $W_T^* \ll \sigma$,

$$W_T = [(1+\gamma) - \sigma(1+\eta)]W_T^* + \sigma, \tag{7}$$

which leads to the equality $W_T = \sigma$ at the absolute zero, according to the definition of the residual resistance. Our tests of platinum resistance in the region of 1.5 - 4.2°K also agree with (7). This limiting case is in the temperature range where platinum thermometry is not applicable.

By means of the successive approximations method it is possible to obtain instead of (5), which relates W_T with W_T^*, a relationship between W_T of a given grade, and W_T^{st} of a standard grade of platinum, for which a detailed smooth table exists [12].

In fact:

$$W_T^{st} = W_T^* + \sigma_{st}(1+\eta_{st})(1-W_T^*) - \frac{\eta_{st}^2 \sigma_{st}^2}{\eta_{st}\sigma_{st} + \gamma_{st} W_T^*}, \tag{8}$$

whence, by expressing approximately W_T^* by means of W_T^{st} we obtain

$$W_T = W_T^k + \sigma(1+\eta)(1-W_T^k) - \frac{\eta^2\sigma^2}{\eta\sigma + \gamma W_T^k}, \tag{9}$$

where

$$W_T^k = W_T^{st} - \sigma_{st}(1+\eta_{st})(1-W_T^{st}) + \frac{\eta_{st}^2 \sigma_{st}^2}{\eta_{st}\sigma_{st} + \gamma_{st}[W_T^{st} - \sigma_{st}(1+\eta_{st})(1-W_T^{st})]}. \tag{10}$$

The values of constants σ_{st}, η_{st} and γ_{st} can be determined independently. The residual resistance of the standard grade platinum was determined by us experimentally in a low pressure liquid helium bath [11] and was found to be $\sigma = 5 \cdot 10^{-4}$. For determining η_{st} let us note that at the normal boiling point of oxygen formula (6) holds, so that $\eta_{st} = \frac{W_{O_2}^{st} - W_{O_2}^*}{\sigma_{st}(1-W_{O_2}^*)} - 1$. Assuming that $W_{-90°C}^* = 1.3928$ (see for instance [6]) and using Stimson's constants for the International Temperature Scale [13] we obtain $W_{O_2}^* = 0.2435$, hence $\eta_{st} \approx 0.1$. The value of γ_{st} can be determined from the condition that Matthieson's rule holds in any case for nitrogen temperatures, so that the third term in formula (5) should not exceed $1 \cdot 10^{-6}$, namely $\eta_{st}^2 \sigma_{st}^2 / (\eta_{st}\sigma_{st} + \gamma_{st} W_T^*) \approx 1 \cdot 10^{-6}$; hence $\gamma_{st} \approx 0.01$.

Thus, $\sigma_{st} = 5 \cdot 10^{-4}$, $\eta_{st} = 0.1$ and $\gamma_{st} = 0.01$. With the knowledge of the constants and using (10) it is easy to compile a table for W_T^k from a table of W_T^{st} [12]. The values of W_T^k are given in Table 4. Intermediate values of $W_T^k(T)$ can be obtained with sufficient accuracy, since $W_T^{st} - W_T^k$ changes but little with T (see Table 4).

The values of constants σ, η and γ for a given thermometer are determined by calibrating them at the boiling points of helium, hydrogen and oxygen. From the following relations σ, η and γ respectively are determined for the calibrated thermometer:

$$\sigma = W_{He} - 25 \cdot 10^{-6}, \tag{11}$$

$$1 + \eta = \frac{W_{O_2} - W_{O_2}^{st} + 5.5 \cdot 10^{-4}(1 - W_{O_2})}{\sigma(1 - W_{O_2}^{st})}, \tag{12}$$

$$W_{H_2} = W_{H_2}^k + \sigma(1+\eta)(1-W_{H_2}^k) - \frac{\eta^2\sigma^2}{\eta\sigma + \gamma W_{H_2}^k}. \tag{13}$$

Thus, when σ, η and γ are calculated from measured values of W_{He}, W_{H_2} and W_{O_2} and the formulas (11),(12) and (13), the evaluation of temperature in the region of 10-90°K amounts to measuring $W_T = R_T/R_{0°C}$ of the thermometer, determining the corresponding value of W_T^k from (9), calculating the corresponding value of W_T^{st} from Table 4 and corresponding T from the $W_T^{st}(T)$ table of [12]. We compared the experimental results obtained for the relation of W_T to T in the range of 10.8-90.19°K for 10 different grades of platinum [3] with the data calculated from (9) thus evaluating the accuracy of the suggested method.

TABLE 4

T°K	$W_T^k \cdot 10^4$	$(W_T^{st} - W_T^k) \cdot 10^4$	T°K	$W_T^k \cdot 10^4$	$(W_T^{st} - W_T^k) \cdot 10^4$
12	527	504	40	41237	522
14	935	507	45	57173	514
16	1570	510	50	74924	505
18	2490	514	55	95726	495
20	3753	519	60	114122	485
22	5415	523	64	136474	474
24	7515	526	70	156068	462
26	10083	528	75	179092	449
28	13133	528	80	199194	437
30	16666	528	85	222308	426
35	27584	526	90	242639	415

The results of this comparison in terms of the temperature equivalent are shown in Table 5. For platinum grades with $\alpha > 0.003923$, the error in the scales calculated by this method in the temperature range above 20°K is of the order of several thousandths of a degree, and in the temperature range below 20°K not exceeding 0.02°. For platinum grades with $0.003918 \leq \alpha \leq 0.003921$, the error does not exceed 0.02-0.03° above 20°K and is up to 0.1° below 20°K. It should be noted that this method is only applicable if the constants in (9) are positive. Thus, the "Pobeda" grade platinum, which has an $\alpha = 0.0039247$, cannot be corrected by this method, since its η has a negative value.

The advantages of this method consist in the fact that it provides an accurate correction for the scales of various platinum thermometers ($\alpha > 0.003923$) in the range of 10-12° to 90.19°K. The thermometers need only be calibrated normally at the boiling points of oxygen and hydrogen and in addition at the boiling point of helium. The calibration at the latter point presents no difficulties for up-to-date laboratories. It should also be noted that the above method is based on modern conceptions of the relation between the resistance of metals and temperature, and is not merely a successfully compiled algebraic formula as are a majority of previously suggested correction methods.

TABLE 5

Grade	IKh-6-11	V	IKh-4	Am-I	R-51	Am-III	Am-II	R-50	IKh-3
α=0.0039	251	250	242	228	215	209	206	205	178
$\sigma \cdot 10^4$	507	460	709	557	1293	909	1227	1337	2109
T°K	$\Delta T \cdot 10^4$°								
12	0	20	0	70	100	160	180	100	–
14	0	10	0	60	80	140	110	80	370
16	0	8	0	35	50	80	60	40	180
18	0	4	5	20	30	40	30	20	60
20	1	1	0	6	0	10	7	0	5
22	3	0	6	4	15	8	2	16	20
24	4	0	7	10	25	20	5	28	30
26	6	2	9	18	30	26	6	34	35
28	6	3	9	20	31	30	5	33	30
30	7	4	12	21	29	29	4	30	26
35	8	2	11	25	27	27	0	28	20
40	6	1	10	20	24	20	5	25	15
45	6	1	8	17	18	15	8	20	10
50	6	0	7	12	13	10	7	15	6
54.36	5	0	5	9	12	6	6	12	5
60	4	1	4	4	6	4	5	9	4
70	3	0	2	0	2	1	3	5	3
80	2	1	1	4	2	1	1	2	2
90	1	2	1	6	1	2	1	1	1

Conclusions. 1. A method for correcting platinum thermometer scales against a standard scale by means of formula

$$W_T = W_T^k + \sigma(1+\eta)(1-W_T^k) - \frac{\eta^2\sigma^2}{\eta\sigma + \gamma W_T^k}$$

is suggested, where W_T^k is a tabulated function of W_T^{st}, and the latter is a function of temperature; σ, η and γ are constants obtained from calibrating the thermometer at the boiling points of helium, hydrogen and oxygen.

The method is only applicable if these constants are positive.

The error obtained after correction by this method of 10 different grades of platinum, which were experimentally investigated earlier [3], amounts to 0.01° in the range of 12-90°K for sufficiently pure grades of platinum ($\alpha > 0.003923$). For less pure grades of platinum the correction error amounts to several hundredths of a degree.

2. Experimentally obtained data [3] of thermometers made of 10 different grades of platinum were compared with the calculated data:

a) Scales calculated by means of the Nernst formula with one constant and the Z-function method (with two constants) were compared with experimental data, thus determining the accuracy and range of applicability of these simple methods;

b) scales of thermometer type IKh-4 calculated by more complex correction methods [5, 6, 7] were compared with experimental data, showing the insufficient accuracy of these methods for this type of platinum;

c) the comparison of scales corrected by Barber's method [8] indicated the unsatisfactory degree of accuracy of this correction method in the 20-90°K range for sufficiently pure platinum. The correction accuracy at temperatures below 20°K is considerably worse than that obtained by the method suggested by the present author.

A. S. Borovik-Romanov participated in the discussion of the results obtained in the present work.

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REPRODUCIBILITY OF THE CHANGE OF PHASE TEMPERATURE OF SOLID OXYGEN

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Oxygen in its solid state has two transformations: $\alpha \rightarrow \beta$ at 23.8°K and $\beta \rightarrow \gamma$ at 43.8°K; the temperature of its triple point is 53.4°K.

The study of the changes of phase in solid oxygen is of interest from the point of view of their use as reference points for temperature scales in the range of 10-90°K. In calibrating platinum resistance thermometers in this range of temperatures a correction method is now widely used which is based on the assumption that the differences in specific resistances of various grades of platinum do not depend on temperature (Matthieson's rule). This rule leads to the formula

$$W_T^* = W_T + M(1 - W_T), \qquad (1)$$

where W_T is the relative resistance of the tested thermometer at temperature $T = R_T/R_0$; W_T^* is the relative platinum resistance value at temperature T taken from the table; M is the coefficient determined at one reference point.

In order to raise the accuracy, instead of one, two reference points can be used. Such a correction formula has the form

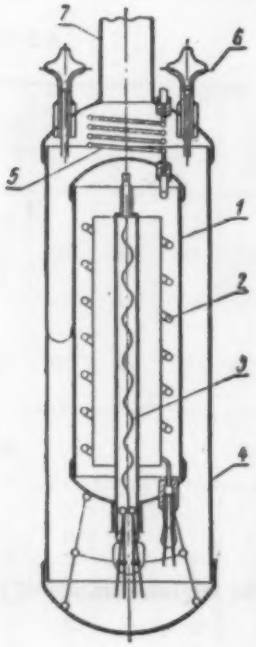
$$W_T^* = k + l W_T, \qquad (2)$$

where k and l are the coefficients determined at two reference points. In the range of 10-90°K such reference points consist of the boiling points of oxygen and hydrogen. The investigation of the relation between resistance and temperature of various grades of platinum has shown that in the range of 30 to 50°K Matthieson's rule no longer holds. Hence in the range of 20-90°K the use of (1) and (2) provides temperature correction with an error of ± 0.05°; below 20°K this error rises considerably. This error can be reduced if the whole range is divided into two parts. For this purpose, it is necessary to have in the middle of the temperature range an additional reference point which can be represented by one of the change-of-phase temperatures of oxygen. Despite a large amount of experimental work in determining the temperature of changes of phase of oxygen, the results so far obtained differ by as much as tenths of a degree, and there are as yet no definite data on the reproducibility of these temperatures.

Below we examine the technique of producing phase-change temperatures of solid oxygen, of determining their reproducibility and their numerical thermodynamic value.

Solid oxygen has a very low thermal conductivity precluding the application of the thermal analysis method. In order to obtain satisfactory results in producing reference point temperatures, the heating-up rate must be extremely small (for instance, in Giauque's experiment [1] the heating up lasted 65 hours).

In order to obtain a high reproducibility of reference points in a short measuring time we used a calorimetric method. In this method [2] a vacuum calorimeter is used (see figure) in which oxygen fills the calorimeter container 1, which is placed in a hermetic casing 4. The whole system is placed in a Dewar flask with a cooling liquid (not shown in the figure). Pure gaseous oxygen is supplied through capillary tube 5. During testing heat is supplied to the oxygen through helix 2, and its temperature is measured by a platinum resistance thermometer. The space between the calorimeter container and the casing is filled with a heat-exchange gas, bringing the calorimeter to the temperature of the bath and liquefying the oxygen. Next the temperature of the bath is lowered and the oxygen is cooled still further and changes to a solid state. Next the space between the calorimeter container and the casing 4 is evacuated to a high state of vacuum. If the temperature difference between the bath and the calorimeter container is not too great, the calorimeter becomes thermally insulated, but not completely, since thermal losses will exist owing to the radiation from the calorimeter container to the bath, conductivity along the electrical conductors 6 and the suspension system, and radiation from the pumping tube 7. As the result of this the calorimeter loses a considerable amount of heat and a temperature "flow" arises; a part of the heat supplied to the calorimeter is used for compensating these losses. Since in determining the phase-change temperatures it was not required to obtain the absolute thermal values of these changes, a method for compensating these losses was used which consisted in making the calorimeter heater fed by a direct current compensate for the heat losses of the calorimeter to the surrounding bath. The compensation current is affected by the temperature of the bath and the phase changes of oxygen. The value of this current was calculated and checked experimentally; depending on the operating conditions it varies between 20 and 40 ma.



Moreover, in order to make the temperature difference between the bath and the calorimeter as small as possible we used in the bath liquid hydrogen for the change of $\alpha \rightarrow \beta$ and solid nitrogen under low pressure for the change of $\beta \rightarrow \gamma$ and for the triple point.

Owing to these precautions we were able to obtain a calorimeter temperature drift of 0.001-0.0006°/min.

For regular calibrations the soldering of the vacuum casing should be replaced by a flanged connection [3], and the thermometer should be inserted with a vacuum paste into a sleeve which is soldered into the calorimeter containing oxygen.

For the measurements we used very pure oxygen obtained from potassium permanganate by disintegrating it at ~ 240°C [4]. Any admixtures in the oxygen, especially those of nitrogen, can displace considerably the phase-change temperatures and the purity of oxygen was, therefore, checked by the coincidence of the readings of two condensation

type thermometers filled with oxygen, which were obtained at different times. Temperature displacements in our experiments did not exceed ±0.003° [5].

Year	Author	T°K	Temperature measured with	Reference
change $\alpha \rightarrow \beta$				
1916	Eucken	23.5	Pb resistance thermometer	[9]
1929	Clusius	23.8	the same	[11]
1929	Giauque and Johnston	23.66	Copper-constantan thermocouple	[1]
1950	Hoge	23.886	Pt resistance thermometer	[12]
1959	Our measurements	23.876±0.006	the same	
change $\beta \rightarrow \gamma$				
1916	Eucken	42.5	Pb resistance thermometer	[9]
1929	Clusius	43.5	the same	[11]
1929	Giauque and Johnston	43.76	Copper-constantan thermocouple	[1]
1935	Aoyama and Kanda	43.70	the same	[13]
1950	Hoge	43.80	Pt resistance thermometer	[12]
1959	Our measurements	43.818±0.004	the same	
triple point				
1911	Onnes and Crommelin	54.7	Pt resistance thermometer	[14]
1911	Dewar	54	Hydrogen gas thermometer	[15]
1916	Eucken	54.1	Pb resistance thermometer	[9]
1929	Giauque and Johnston	54.39	Copper-constantan thermocouple	[1]
1931	Justi	54.24	Resistance thermometer	[16]
1935	Aoyama and Kanda	54.40	Copper-constantan thermocouple	[13]
1935	Lisman and Keesom	54.325	Pt resistance thermometer	[17]
1936	Henning and Otto	54.33	Helium thermometer	[18]
1950	Hoge	54.363	Pt resistance thermometer	[12]
1959	Our measurements	54.365±0.004	the same	

The temperature was measured by a platinum resistance thermometer [6] made of platinum grade IONKh-3 with $R_{100}/R_0 = 1.39191$. It was calibrated at boiling temperatures of oxygen and hydrogen: $R_{O_2}/R_0 = 0.245495 \pm 0.00004$; $R_{H_2}/R_0 = 0.006744 \pm 0.00002$ [6]. The same grade of platinum was used for making other thermometers which were calibrated against a gas thermometer, and a smoothed-out calibration table was compiled for grade IONKh-3 platinum in the range of 10-90°K in steps of 1°. Moreover, from the study of the properties of this platinum it was found that Matthieson's rule applies to it down to 35°K. This provided a possibility of relating the above thermometer with the thermodynamic scale.

The phase-change temperatures were determined by the maximum thermal capacity. The duration of the changes amounted to 30' for the change of $\alpha \rightarrow \beta$ and up to 50' for changes of $\beta \rightarrow \gamma$. Owing to the large conversion heat the upper point of 43.8°K was very stable; during half an hour it varied by about 0.001_5°.

For the temperature of change $\alpha \rightarrow \beta$, which cannot be used in thermometry owing to its proximity to the temperature of the hydrogen boiling point and its small latent heat of conversion, a value was obtained out of 5 measurements amounting to 23.876±0.006°K.

For the temperature of change $\beta \rightarrow \gamma$ out of 5 measurements a value was obtained equal to 43.818 ± 0.004°K.

For the triple temperature point out of 10 measurements the following value was obtained: 56.365 ± 0.004°K.

The last two phase changes serve as reference points in determining a temperature scale below 90°K. The latent temperature of the phase change for both these cases is large and in using the loss-compensation method it is possible to maintain a constant temperature during a long time.

The temperature values are given in degrees of the practical VNIIFRTI (All-Union Scientific Research Institute of Physicotechnical and Radiotechnical Measurements) scale (T_{prac}). The thermodynamic temperature can be determined from formula [7]

$$T_{ther} = T_{prac} + T_{prac}\,[(T_{O_2} / 90.19) - 1] \pm 0.006°.$$

This formula takes account of the possible measurement of the oxygen point temperature T_{O_2}.

It should be noted that the values of phase-change temperatures were published earlier [8], but their values were given in degrees of a nominal scale which could differ considerably from the thermodynamic scale. The values of the phase-change temperatures determined in 1954 and 1959 differ by the following amounts: for the change of $\alpha \rightarrow \beta$ by + 0.006°, for $\beta \rightarrow \gamma$ by + 0.018°, and for the triple point by −0.004°.

The 1959 data are more reliable and have been collated in a table. The considerable difference at the temperature of 43.8°K is due to the nominal scale not being based directly on gas thermometer measurements, and the shape of the $\Delta W(T)$ curve not being known. The temperature was determined by means of Matthieson's rule and a table for another grade of platinum; the error of determining the temperature by this means could reach ± 0.03°.

The table provides values of the phase-change temperatures of solid oxygen and at the triple point.

A study of the table shows that our measurements are very close to those of Hoge. Differences of the order of 0.02° for the change of $\beta \rightarrow \gamma$ are probably due to the difference in the practical scales used by the authors. It follows from [10] that this difference should not exceed 0.01°. It should be noted, however, that Hoge's measurements were made by means of a calorimeter with a very large mass, and that the temperature of the change of phase $\beta \rightarrow \gamma$ was changing slowly. The author notes that in a 10 minute period of the change of phase the temperature varies by 0.03°; moreover, the temperature of the change of phase also depends on imbalances and temperature gradients in the oxygen sample. All this makes the determination of the phase-change temperature of $\beta \rightarrow \gamma$ rather uncertain.

Conclusions. 1) For the study of the reproducibility of the change of phase temperatures of solid oxygen a calorimetric method was suggested and a simplified vacuum calorimeter was made with a compensation of heat losses, thus providing a temperature variation in the calorimeter < 0.001-0.0006°/min.

2) By means of this technique the phase-change temperatures suitable for thermometry can be produced with an error up to 0.004°.

3) Numerical values for change of phase temperatures of solid oxygen and at the triple point were obtained in terms of the practical VNIIFTRI scale.

The numerical values in degrees of the thermodynamic scale are determined with the accuracy of the formula, which accounts for the possible difference between the practical and thermodynamic scales, and the possible variation in the boiling temperature of oxygen.

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DIFFERENTIAL INSTRUMENT FOR COMPARING RADIATION PYROMETERS

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Most commonly used device for calibrating and checking radiation pyrometer telescopes is a type URP-4 tester whose radiation source is a movie lamp, with a condenser lens that produces the radiator's image on the pyrometer objective. The pyrometers being compared are mounted in special holders which make it possible to place them in turn in exactly the same position in front of the radiator along the optical axis of the system. However, owing to an insufficiently rigid location their position may vary, producing a nonuniform luminous flux, thus leading to a systematic error in comparing the telescopes. In order to avoid the possible differences in the position of telescopes with respect to the luminous flux when checking reference pyrometers, the position of the telescopes is interchanged during testing.

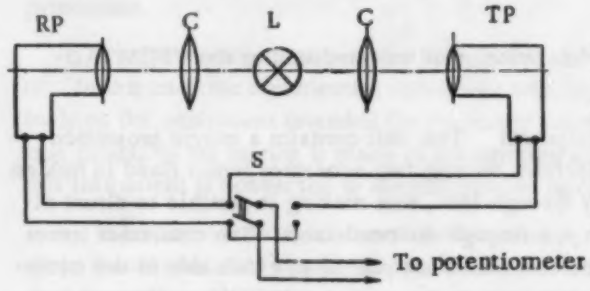

Fig. 1.

The lamp which serves as a radiator in the URP-4 set is fed from the ac mains through a stabilizer or from powerful storage batteries. In order to be able to set the temperature as closely as possible to round hundredths of degrees so as to reduce the conversion error, it is necessary to provide a continuous smooth control of the lamp current. For this purpose an auxiliary rheostat is used in addition to the variac incorporated in the set.

The set temperature value, however, does not remain constant during measurements owing to the voltage variations which occur despite the stabilizer. Moreover, the variations are so large that the operator is obliged constantly to control the current by means of the rheostat, in order to keep the readings of the reference pyrometer as close as possible to the value of the thermal emf shown in the calibration characteristic. In order to avoid the error due to the voltage instability it is necessary to make several measurements at one temperature for each of the compared pyrometers. In processing the test results mean values of the reference and tested instrument readings are obtained; the thermal emf of the tested pyrometer at a nominal temperature is then computed from the above data. Thus, testing by means of set URP-4 is labor-consuming and even experienced state inspectors can only test one reference or four commercial pyrometers per shift.

In order to make the work easier both the URP-4 set itself and the method of checking pyrometers need to be improved.

With this in mind we proposed a differential method of comparing radiation pyrometers. In this method the compared pyrometers are sighted on the radiator simultaneously, and not one at a time as in the URP-4 set. The pyrometers are placed on either side of the radiator in such a way as to obtain an equal luminous flux. At the same

time the difference between their thermal emfs is measured directly by connecting the electrical circuits of the reference and tested pyrometers differentially.

The schematic of the equipment for a differential comparison of radiation pyrometer telescopes is shown in Fig. 1. The luminous flux is directed from lamp L through condenser lenses C to the objectives of the pyrometers being compared. The electrical circuits of the compared radiation pyrometers are connected to switch S, which connects them to dc potentiometer for measuring their thermal emfs. In the left-hand position of the switch the potentiometer measures the thermal emf of the reference pyrometer. The radiation temperature at which the comparison is made is found from the known calibration characteristic of the reference pyrometer. In the right-hand position of the switch the thermal emf difference between the checked and reference pyrometers is measured. By adding this difference with the corresponding sign to the value of the reference pyrometer emf given in its certificate, the emf of the tested instrument is obtained at the temperature given in the certificate and the calibration characteristic of the tested instrument is obtained by means of very simple computations. The luminous fluxes fed to the reference (RP) and tested (TP) pyrometers may not be equal, and the positions of the telescope should be interchanged or the radiator should be turned through 180° and the difference should be measured twice for each position. The mean value of the two readings eliminates the error introduced by the inequality of the luminous fluxes. In adjusting the equipment, this inequality can be reduced to a minimum by the method outlined above.

This equipment is used normally for comparing instruments of a similar type which have similar calibration characteristics. Hence, the difference in the thermal emfs of the telescopes changes relatively little with temperature and can be measured at temperatures close to those given in the certificate. Thus, it is not necessary either to measure or maintain accurately the temperature at which the measurements are made and the voltage stabilizer and additional rheostat can be dispensed with.

In addition to simplifying the measurement procedure and the processing of test results the differential method also eliminates the effect of the voltage source instability on the measured difference of the tested pyrometers' thermal emfs. The voltage variations of the lamp as well as the variations caused by the instability of contacts in the control device affect equally the thermal emfs of both the compared pyrometers and, therefore, do not affect the difference in their thermal emfs. This makes the operator's work much easier and more reliable, since he only has to record the values of the thermal emf difference, which does not vary with time. It is no longer necessary to take a large number of readings or to readjust constantly the current through the lamp in order to maintain the reference pyrometer thermal emf constant at a set value.

A test set type URD* for differential comparisons of radiation pyrometers was produced at the VNIIM (All-Union Scientific Research Institute of Metrology).

The rotating radiator unit is placed at the center of the equipment. This unit contains a movie projection lamp which transmits luminous fluxes to the tested pyrometer objectives through two condenser lenses fixed in holders on the side walls of the unit. This unit can be rotated accurately through 180°, thus making it possible to direct alternately at the same instrument different luminous fluxes which pass through the condensers. The condenser lenses can be displaced along the optical axis of the instrument. The holders which are placed at either side of the equipment have devices which make it possible to set the instruments they hold to the optical axis of the equipment and to move them along this axis. The telescopes are sighted in a manner similar to that used in the URP-4 set against the central part of the condenser lens, which is surrounded by a black circle.

The initial adjustment of the equipment consists of three operations:

1. The telescope and lamp are first set approximately to the optical axis of the condensers. White paper screens are placed in front of the telescopes and the lamp is adjusted for an approximately equal position of the condensers so as to obtain symmetrical images of its filament in the telescope objectives as shown on the screens placed in front of them. When this unit is turned through 180° the images must remain symmetrical. The screens are then removed and the measuring circuit switched in. The measuring instrument in the URD set consists of a semiautomatic potentiometer type R-2, which provides a sufficiently accurate measurement of relatively small thermal emf

*The equipment was made according to the drawings of designers L. S. Levin and L. A. Turchaninova and was adjusted by mechanics A. D. Demkin and L. S. Smirnov.

differences. Various positions of the switch provide measurements of the thermal emfs of each pyrometer separately and the difference between that of the reference and tested pyrometer for its positive or negative value.

2. By adjusting the condenser lenses equal readings of the reference pyrometer in the two positions of the radiator should be obtained. Then for the two positions of the radiator rotated through 180° the two readings of the tested pyrometer will also differ very little from each other.

For a correct adjustment of the equipment it is possible to obtain a flux symmetry for which the turning of the unit through 180° will alter the pyrometer readings by not more than 2-3°C for the top limit (1800°C) and by 5-8° for the bottom limit (900°C), i.e., the readings will differ from the average by not more than 2-4°C.

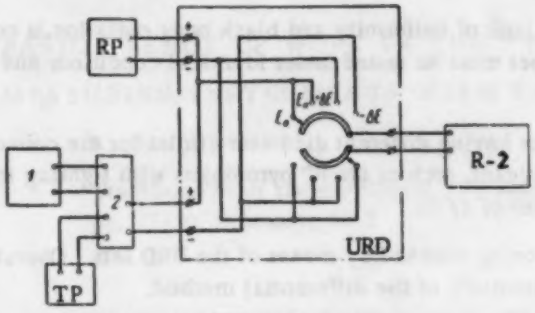

Fig. 2. Schematic of electrical connections for testing commercial radiation pyrometers on the URD set. 1) Millivoltmeter; 2) substitution panel.

3. In order to check the symmetry of the pyrometers with respect to the radiator, it is ascertained that the thermal emf difference hardly changes when the position of the telescopes is interchanged.

All the above tests aimed at obtaining a sufficiently high sensitivity should be made at a temperature approaching the top measuring limit.

The experimental URD set was used for comparison tests of a group of original VNIIM reference radiation pyrometers types TERA-50 and RP, which had been calibrated by means of a "black body" radiator. The calibration characteristics of these instruments obtained by the comparison method differed on an average by ±4°C from those obtained by calibrating against a "black body" radiator.

The same equipment was used for calibrating 65 reference grade III radiation pyrometers. Each of these pyrometers was compared with two reference instruments of the initial group. The divergencies obtained in comparing the various reference instruments did not exceed 10°C at any point of the calibration characteristics, i.e., the deviations from the average did not exceed 5°C. All these tests show that in addition to speeding up the testing and simplifying the equipment the differential method provides a higher accuracy in comparing the thermal emfs of pyrometers.

The URD equipment can also be used for checking commercial radiation pyrometers types TERA-50, R-3 and RP. In this case the commercial pyrometer telescope is connected together with the substitution panel and the terminals on the equipment intended for the tested instrument are connected to the appropriate terminals of the substitution panel. If the testing is made in conjunction with a millivoltmeter or any other electrical measuring instrument, this instrument is connected to the substitution panel (Fig. 2).

In testing commercial instruments against a reference one stricter temperature setting conditions are required, since their calibration characteristics differ considerably (about 30%). In order to be able to consider that the measured thermal emf difference does correspond without any additional computation to the given nominal temperature T, the latter should be set within the limits of T± (10-15)°C in order to keep the error of checking commerical instruments within the limits of 3-5°C. For instance, when checking the calibration of R-3 type instruments, the thermal emf of the reference instrument should be set at 900°C with a deviation not exceeding 0.1-0.2 mv and at 1800°C with a deviation not exceeding 1-1.5 mv of the thermal emf values given in the certificate.

In checking commercial radiation pyrometers it is possible to measure the difference between the voltages of the reference and tested pyrometer only in one position of the radiation unit, if it has been ascertained in advance that the reversal of the radiator at temperatures near the top measuring limit of the pyrometers does not produce a difference greater than 2-4°C in the reading of the reference, and 5-7°C in the reading of the tested pyrometer.

The test results are processed in the same manner as for reference pyrometers, i.e., at any given point of the scale the difference ΔE, which is measured on the equipment at temperatures approaching the nominal, is added with the appropriate sign to the datum E_0 given in the reference instrument certificate. The resulting voltage E_n for this point of the scale will be

$$E_n = E_0 + \Delta E.$$

The experiments carried out with the URD equipment at the VNIIM showed that the productivity in testing radiation pyrometers by means of this set was 5 times greater than that provided by the URP-4 type set.

If the "tare"* method is used, the productivity in checking rises by a factor of 10. The "tare" method as applied to the URD set consists in comparing an auxiliary instrument, the tare, connected to one side of the equipment, first with a reference telescope and then with the telescopes under consideration which are connected in place of the reference pyrometer, i.e., on same side of the equipment. The "tare" is in a way marked off by the value of the reference instrument, thus avoiding the necessity of an accurate adjustment for equal fluxes when the radiator is turned through 180°. The error in comparing reference instruments does not exceed 3-5°C, i.e., it is half that obtained with the URP-4 set.

However, the basic defect of set URP-4, consisting in the lack of uniformity and black body radiation, is not eliminated in the URD set and, therefore, the compared telescopes must be tested under identical conditions and must be of a similar type.

The equipment is supplied with two sets of condenser lenses having different diameter circles for the convenience of checking radiation pyrometers with different sighting indexes, such as the RP pyrometers with sighting indexes of 1/16 and the RAPIR (TERA) pyrometers with sighting indexes of 1/20.

At present all the instruments delivered to the VNIIM are being checked by means of the URD sets. Operational tests have confirmed the above data on the accuracy and productivity of the differential method.

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DEFECTS IN THE DIFFERENTIAL MANOMETERS MADE BY THE "TEPLOKONTROL' " KAZAN' PLANT

A. D. Snagovskii

Translated from Izmeritel'naya Tekhnika, No. 2,
p. 26, February, 1961

The "Teplokontrol' " Kazan' Plant makes differential manometers types DP, DPSÉ supplied with measuring instruments É-610 and É-612.

The induction coils of these instruments are wound on carbolite formers which often break in transport, so that new instruments have to be repaired straight away, and if no spare coils are available they become inoperative.

On the other hand the KIP Khar'kov Plant produces similar instruments with aluminum coil formers.

The "Teplokontrol' " Plant should wind its coils on aluminum formers.

* The above "tare" method for a differential comparison of telescopes was suggested by the KhGIMIP (Kharkov State Institute of Measures and Measuring Instruments).

ELECTRICAL MEASUREMENTS

Considering the importance of the work carried out by the "Vibrator" Plant in producing electrical measuring instruments with torsion suspensions, and the considerable interest aroused by these instruments, we publish below a series of articles which consist of abridged versions of certain papers read by their authors at the first Scientific-Technical Conference which was organized by the "Vibrator" Plant in October, 1960, to discuss the work carried out by the plant in designing and producing these instruments (Measurement Techniques, No. 11, 1960, p. 62).

BASIC TRENDS OF WORK IN THE "VIBRATOR" PLANT ON ELECTRICAL MEASURING INSTRUMENTS WITH TORSION SUSPENSIONS

A. M. Damskii

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The important requirements raised by our national economy with respect to electrical measuring instruments demand a radically new approach to a number of problems in designing these instruments.

Among these problems one should cite in the first case the raising of sensitivity, accuracy, shock- and vibration-resistance, stability, speed of operation and economy in use of electrical measuring instruments.

One of the greatest obstacles in raising the sensitivity of the instruments in the past century has consisted in overcoming the friction of their bearings (the pivot-jewel pair). It is not by accident that the generally accepted criterion of the quality of measuring mechanisms, the Q-factor, is characterized exclusively by the value of friction in the instrument. In order to increase this coefficient the torque of the instrument is normally raised, and hence the power consumed by the measuring mechanism. In moving coil instruments the torque is raised mainly by increasing the size and improving the quality of magnets, and hence raising the cost of the instrument. In moving iron, ferrodynamic, electrodynamic and other instruments this is achieved by raising their power consumption, etc. Thus, the friction in the bearings of electrical measuring instruments limits their sensitivity. This fact is confirmed by the data given in the table attached.

Parameters	Pivot instrument	Torsion suspension instrument
Current constant (dc), amp/mm	10^{-7}	10^{-9} (with amplifier 10^{-11})
Voltage constant (dc), v/mm	10^{-5}	10^{-6} (with amplifier 10^{-8})
Consumption and voltage drop in ac instruments	-	Smaller by a factor of 5-10
Frequency range	-	Greater by a factor of 2-3
Damping time, sec	0.5- 1	0.1 - 0.2
No. of connections (life)	-	Considerably larger
Resistance to shocks	-	Considerably larger
Grade of accuracy	0.1 - 0.2	0.05 - 0.1

In modern practice requirements arise daily for checking and measuring instruments with a sensitivity exceeding that of pivot instruments by 1000 times. The complicated measurements made on the spot in production shops or under field conditions require highly sensitive portable and rack-mounted instruments which are not mounted on

a foundation or a wall in the manner of sensitive galvanometers. This provides an explanation for the increasing use in our national economy of rack-mounted microammeters, millivoltmeters, low-range electrostatic meters, microohmmeters and other instruments.

The shockproof and vibrationproof requirements are no less important, especially if the high sensitivity of instruments is preserved. Owing to the large friction in the pivot-jewel pair it is often impossible to make the instrument sufficiently vibration-and shockproof, whereas in many cases it is precisely the measuring instruments which are the controlling factor in the reliability of a system as a whole. In order to raise the instruments' shockproof and vibrationproof properties it is often necessary, as in the preceding case, to increase their power consumption. This, in turn, leads to a larger size and weight.

The considerable amount of work carried out in the last ten years at the "Vibrator" Plant in the sphere of microtechnology, i.e., in the production of components of a minimum size, and in the first place great improvements in the quality of torsion suspensions, has made it possible to design and manufacture the greater part of electrical measuring instruments on torsion suspensions.

It should be noted that the application of such measuring mechanisms provides basically new properties for the instruments. Thus, for instance, owing to torsion suspensions it is now possible to use in sensitive instruments,instead of the moving coil,the induction, moving iron, electrostatic, moving magnet and other technically advanced systems, which until recently were considered insufficiently sensitive.

Measuring instruments with torsion suspensions, owing to their principle of operation which provides no friction, also possess the smallest initial error.

As the result of the work carried out in this respect it has been possible to design instruments with torsion suspensions both of the laboratory and rack-mounted types, which possess highly desirable operational properties.

Extensive work in this sphere leads to the conclusion that further progress in raising the sensitivity, accuracy, stability, shockproof and vibrationproof properties, speed of operation, and reducing the weight of electrical measuring instruments will be achieved mainly by designing and producing their moving parts on torsion suspensions.

The research carried out in recent years at the "Vibrator" Plant in the sphere of microtechnology, the design of instruments and organization of their production, has led to the mass production of several new types of highly efficient electrical measuring instruments. Thus, miniature laboratory grade 0.5 instruments have been designed and their production organized. Owing to the use of magnetic systems with a magnet inside the coil frame, of torsion suspensions, of newly produced wire-wound microresistors and the latest improvements in the semiconductor technique, these instruments have been made considerably lighter and smaller, yet with improved technical characteristics.

The factory has also mastered the production of a new series of moving-coil galvanometers, which preserve the high quality of the previous type with a reduced size. This has been made possible by the use of new types of glass-insulated wire a few microns thick.

The plant has completed the design and started production of a new series of grade 0.2 and 0.1 instruments, in which, owing to the replacement of pivot bearings by torsion suspensions, the use of magnets inside the coil frames and the application of semiconductor elements for temperature correction, it has been possible to reduce the size and weight to 2/3 of their former value and to improve considerably the instruments' operational properties.

Up to the present torsion suspensions have been used for instruments of 0.5 grade or lower, and the higher grade instruments were made mainly on pivots; the factory now considers it advisable, however, to make grade 0.1 instruments on torsion suspensions as well.

The plant has developed and put into production for the first time in our country rack-mounted, highly sensitive , multi-range, luminous display microammeters. Highly sensitive, rack-mounted, torsion-suspension panel instruments types M130 - M132 have been developed and are now being put into mass production.

A new trend in electrical instrument-making consists in the development of highly sensitive precision photocompensated instruments and amplifiers. These instruments are based on measuring mechanisms consisting of torsion-suspension galvanometers with photocells and simple optical systems.

Among the instruments of this type produced at the present time one should note the F16 and F116 microvolt-ammeters, which are superior to the best type mirror galvanometers in their voltage sensitivity and other parameters. In addition to registering the current and voltage, these portable instruments also provide a recording of the measured values. The photo-compensated comparators F13, which also use torsion-suspended measuring mechanisms, provide highly accurate (0.02-0.15%) measurements of current, voltage and power at commercial frequency.

The multirange voltage stabilizers U1136 and U1199, which provide a constant voltage across a load with an error in practice not exceeding 0.02% for any mains voltage or load, and highly sensitive, rack-mounted, photo-compensated amplifiers F115, whose power consumption from the measured circuit is insignificant and whose measurement error is of the order of 0.1%, are now made by the plant.

In the near future the plant will start production of photoelectric fluxmeters type F18, whose sensitivity will be 500 times greater than that of an ordinary pointer fluxmeter.

In addition to producing the abovementioned photo-compensated instruments, the plant also manufactures as separate units galvanometric photoelectric amplifiers types F11, F12 and F117, which constitute the sensing elements of all the abovementioned instruments.

By making use of torsion-suspended measuring mechanisms the plant has been able to develop and start production of a number of high-frequency instruments, including thermal ammeters and voltmeters, as well as electrostatic instruments for measuring voltages up to 75,000 v. The new high-frequency thermal ammeter T14 uses ferrites in the cores of its current transformers.

The high stage of development of vacuum converters has made it possible to develop and put into production a new series of thermal instruments. The plant produces a series of thermal voltmeters types T16 and T17, which are highly sensitive and accurate. In the near future the plant will produce new thermal ammeters type T18 for currents up to 50 amp and direct connection into the circuit for highly accurate measurements in the range from tens of cycles per second to several megacycles.

Work carried out by the factory in obtaining torsion suspensions with improved characteristics has made it possible to develop oscilloscope galvanometers with improved mechanical and operational characteristics.

The development and manufacture of torsion suspension instruments are based on research in the sphere of the industrial application of high-quality torsion suspensions. As the result of the work carried out at the plant, new alloys with excellent physical and mechanical properties have been found for the use in suspensions in a relatively short time. Special equipment, technology, standards and tolerances have been developed, and a large-scale centralized mass production of torsion suspensions for the instrument-making plants of the whole of the Soviet Union has been organized.

In this connection the number of elastic element types has increased in the factory sixfold as compared with 1950, and at present amounts to over 400. Moreover, the designers and customers can select torsion suspensions made of materials having different properties.

For the purpose of the fullest utilization of the experience gained at the plant a new GOST (All-Union State Standard) 9444-60 for torsion and ordinary suspensions has recently been established.

In addition to the quality of torsion suspensions, the problem of their fixing is also of great importance. The technical characteristics of the strain springs and the design of supports have a decisive influence on the operation of the torsion suspension in an instrument. The factory pays considerable attention to improvement in the method of fixing the suspensions and torsion springs for instruments of various types. Special sets have been constructed for the testing of torsion suspensions, supports and tension springs.

In 1947 the plant produced 2 types of portable torsion-suspension instruments, in 1960 it produced 31 types.

Of all the laboratory and portable instruments at present produced by the plant, only 7 types use measuring mechanisms on pivot bearings.

Since 1957 the plant has been developing and putting into production rack-mounted torsion-suspension instruments. Prior to 1957 the plant did not produce a single rack-mounted torsion-suspension instrument. Since 1957 these instruments are being mass-produced, and at present 34% of all the rack-mounted instruments have their moving parts on torsion suspensions.

The State Standard for torsion suspensions, developed by our plant and introduced for the first time in the history of the electrical instrument-making industry, and the conveyor-belt production of instruments with these suspensions, bear witness to their wide application in our industry.

The use of torsion suspensions also makes it possible to reduce the weight and size of the instruments. Thus, whereas a grade 0.5 moving coil instrument on pivots weighs 4.5 kg including 1 kg for its kinetic system, the same type of instrument with a magnet inside the moving coil frame and a torsion suspension only weighs 2.8 kg and its measuring mechanism weighs 0.05 kg. Owing to this difference the plant has been able to save in a short period some 12 tons of valuable magnetic steel.

One more circumstance which is usually overlooked should also be noted. It concerns the size of panel and rack-mounted instruments, and in the first place those used with low-power sources, which require considerable expenditure on amplifiers, an increased size of panels, etc., owing to the lack of sensitivity in the measuring instrument. This leads to a considerable increase both in the size and the cost of devices used in conjunction with these instruments. The use of miniature torsion-suspension instruments with their low power consumption provides in this instance a considerable technical and economic saving.

The first scientific and technical conference held in October 1960 on the results of the work carried out by the "Vibrator" Plant in designing and manufacturing electrical measuring instruments with torsion suspensions has attracted the attention of wide circles of engineers working in the electrical instrument-making industry. Noting the considerable success attained in the sphere of computing, designing and producing torsion-suspension instruments, the conference also noted that the tempo of such work at certain plants does not correspond to the advantages which can accrue from the introduction of this new method. In particular the possibilities of raising the reliability and viability of instruments on torsion suspensions are not fully utilized. The theoretical basis for computing and designing torsion-suspension instruments is developing very slowly. Insufficient attention is being paid to computing the economic advantage obtained from using torsion suspensions. The normalization and standardization of the components for fixing torsion suspensions are developing slowly, thus leading to a nonuniformity in their application and impeding their rapid adoption in instruments. The conference outlined several measures for overcoming these defects.

It is necessary to speed up the establishment of a criterion for the quality of torsion-suspension instruments similar to the quality-factor adopted for pivot instruments.

In our opinion such a criterion can be represented by the formula suggested in [1].

The most important tasks facing the "Vibrator" Plant and other factory personnel designing and producing torsion-suspension instruments consist of:

developing theoretical foundations for the operation of torsion-suspension instruments;

designing measuring instrument circuits with the use of the new measurement devices (temperature compensation, etc);

development of the technological foundations for designing torsion-suspension instruments (methods of fixing);

improving the production technology of microcomponents (torsion suspensions, ordinary suspensions, etc.);

developing the technology of assembling torsion-suspension instruments;

solving the problem of balancing, and of mechanical and electrical ageing;

evaluation of the economic benefits due to using torsion-suspension instruments;

the further normalization of components and units in measuring instruments;

mechanization and automation in the production of components and units for torsion-suspension instruments.

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PHYSICOMECHANICAL PROPERTIES OF TORSION SUSPENSIONS FOR ELECTRICAL MEASURING INSTRUMENTS

Z. A. Timofeeva and T. G. Petrova

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 30-32, February, 1961

For the first time in the world history of instrument-making, from January 1961 an All-Union State Standard has been introduced in the USSR for torsion and ordinary suspensions GOST 9444-60. Electrical Measuring Instruments. Torsion Suspensions and Suspensions).

The basic characteristics of torsion suspensions have thus been standardized, including the restoring torque, elastic fatigue and electrical resistance. These data on torsion suspension are, in the majority of cases, completely sufficient for computing and designing electrical measuring instruments.

In designing high-precision or special-purpose instruments which have to operate under difficult climatic conditions it is important to have, in addition to standardized characteristics of torsion suspensions, also data on their tensile strength, elastic limit, normal modulus of elasticity, coefficient of rigidity, limiting current density, thermal emf between the suspension and copper, and the relation of these characteristics to ambient temperature.

It was found in practice that the physicomechanical properties of materials in microcomponents differ considerably from those obtained in reference books, which are normally determined for larger size components.

Characteristic of Torsion Suspensions Made According to GOST 9444-60

Torsion suspension material	Microhardness HV	Tensile strength, σ_t	Tensile limit of proportionality, σ_p	Normal modulus of elasticity, E	Coefficient of rigidity, G	Elasticity temperature coefficient, $\alpha_E \cdot 10^{-4}$, per °C (in the range of −40°C to +100°C)	Elastic fatigue β, in % of the twist angle	Temperature coefficient of the elastic fatigue, $\alpha_\beta \cdot 10^{-2}$, per °C (in the range of −40°C to +40°C)	Resistivity ρ, ohm · mm²/m	Resistance temperature coefficient, $\alpha_\rho \cdot 10^{-4}$ per °C		Linear temperature coefficient, $\alpha_l \cdot 10^{-6}$	Thermal emf between the suspension and copper, μ v/°C
		kg-wt/mm²								at +40°C	at +100°C		
BrSnZn4-3	250	115	80	11500	4500	−4.5	0.1	+0.7	0.09	9.5	15.5		2.0
BrBe2	400	160	100	13500	5000	−3.0	0.2	+0.9	0.06	15.5	15.4		1.0
PtAg20	575	200	160	17500	7000	−2.5	0.05	−1.2	0.3	10.5	14.5		8.0
Co40NiCrMoV	800	300	190	21000	8000	−3.0	0.02	−5.5	1.0	3.0	15.0		1.0

The torsion suspensions made in microsizes according to GOST 9444-60 use such materials as PtAg20 and Co40NiCrMoV, whose characteristics are not given in existing reference books. Neither do the reference books include some of the characteristics important in instrument-making, for instance, the elastic fatigue in strips and wires after twisting.

It was, therefore, necessary to conduct special research into the physicomechanical properties of torsion suspensions. Tests were carried out on standard torsion suspensions made of BrSnZn4-3, BrBe2, PtAg20 and Co40NiCrMoV. Their length was chosen according to the requirements of the particular characteristic to be measured and amounted to 10, 25, 75 or 100 mm. The variation of the sample properties with respect to temperature was measured in the range of -50°C to +100°C.

The tensile strength σ_t, the limit of proportionality σ_p and the normal modulus of elasticity E were determined on a test machine type Mi44 from a photographic reproduction of torsion-suspension strain diagrams.

The mean values of tests made on a large number of samples are given in the table attached, from which it will be seen that the cobalt-chrome-nickel alloy torsion suspensions possess the highest strength and elasticity.

The relation of tensile strength, the limit of proportionality and the normal modulus of elasticity to temperature was also determined on the test machine type Mi44, which is equipped with special cooling and heating devices. These relations are given in Fig. 1.

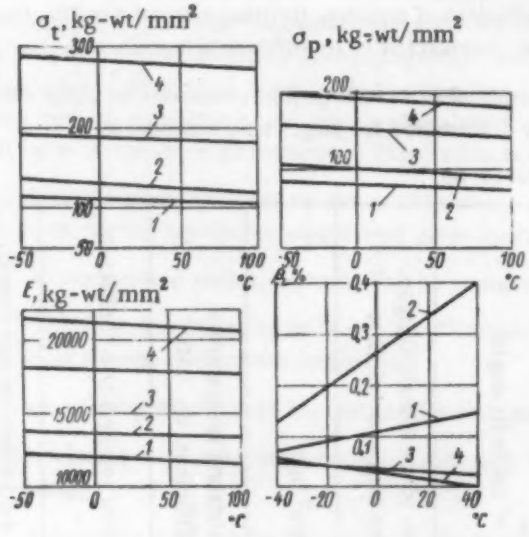

Fig. 1.

It will be seen from Fig. 1 that the tensile strength and limit of proportionality of all the material under investigation* decrease proportionally to rising temperature. The variations in these characteristics are small and are about the same for all types of torsion suspensions.

The elasticity temperature coefficient was calculated by the variation in the value of the torsion suspensions' restoring torque with respect to the test temperature.

It was found to be negative for all the materials but differed in its value. The torsion suspensions made of BrSnZn4-3 had the largest elasticity temperature coefficient.

The torsion suspensions' elastic fatigue β was measured by means of instrument type U1003 [1] and determined as the deviation of the luminous marker from zero after the untwisting of the torsion suspension.

The testing technique consisted of the following: sample torsion suspensions 10 mm long were twisted through angles of 90° and 180° and were kept in that position for 2 hours.

The relations of the torsion suspensions' elastic fatigue to the sample length, to the duration of its twisted exposure, and to the angle of twist are not shown in this article, since they have been given in [2].

The temperature coefficient of the elastic fatigue was determined in the range of -40°C to +40°C.

The bottom right-hand graph of Fig. 1 shows the relation of the elastic fatigue to the test temperature.

The temperature coefficient of the elastic fatigue of the bronze type BrSnZn4-3 and BrBe2 torsion suspensions is positive in the above temperature range, whereas that of alloys type Co40NiCrMoV and PtAg20 is negative. The values of α_β for all the materials are given in the table.

The electrical resistance of the torsion suspensions was measured on a Wheatstone bridge. The resistance temperature coefficient was measured in an oil bath at temperatures of +10, +30 and +40°C.

*In all the graphs the parameters of torsion suspensions made of the same material are denoted by the same figures as shown below: 1) BrSnZn4-3; 2) BrBe2; 3) PtAg20; and 4) Co40NiCrMoV.

Tests have shown that torsion suspensions made of Co40NiCrMoV have the smallest electrical conductivity. This drawback, however, is compensated by their small resistance temperature coefficient.

In certain cases when designing electrical measuring instruments–for instance, electrostatic instruments–it is important to know the current density in the torsion suspensions.

The maximum permissible current density is understood to have a value at which no changes in the physico-mechanical properties of the torsion suspensions are noticeable.

The permissible and disturbing currents for all the samples were determined in an identical manner: their test length was 75 mm, and they were tensioned 25% below the yield point tension of the torsion suspensions.

Figures 2a and 2b show the relation of the disturbing current density j_{dis} and the permissible current density j_{per} to the restoring torque W. Tests have shown that the value of the permissible and disturbing current density for torsion suspensions with a restoring torque less than 4-5 mg-wt·cm/90°, as specified by GOST 9444-60, depends to a great extent on the restoring torque. For torsion suspensions with a restoring torque of from 4-5 to 10 mg-wt·cm/90° this effect is insignificant.

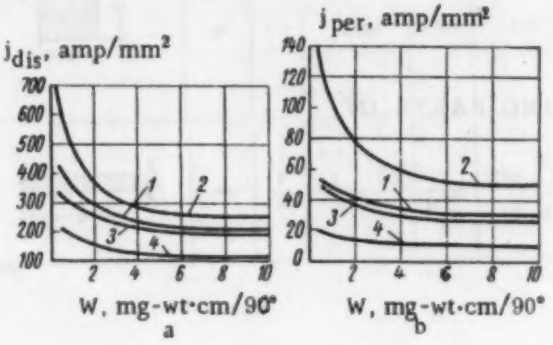

Fig. 2.

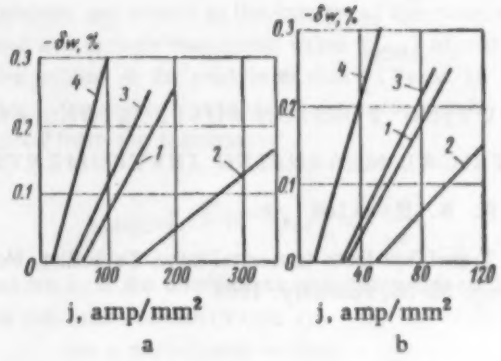

Fig. 3.

Figure 3 shows the relationship between the variation $-\delta W$ in the restoring torque for W = 0.5 mg-wt·cm/90° (a) and for W = 10 mg-wt·cm/90° (b) of torsion suspensions to the density j of the current flowing through them. This relationship can be expressed by linear equations with different slopes.

The largest permissible current density is provided by torsion suspensions type BrBe2.

The thermal emf of sample suspensions against copper was measured at 80°C. It will be seen from the table that torsion suspensions made of PtAg20 had the largest emf.

The linear temperature coefficient of the torsion suspensions was measured on a differential dilatometer type DR 1949.

Torsion suspensions type PtAg20 have the smallest linear temperature coefficient and suspensions type BrSnZn4-3 have the largest coefficient.

Conclusions. At present the Soviet instrument designers have an extensive available range of torsion suspensions for measuring instruments made according to GOST 9444-60 of four materials with any required values of restoring torque, in the range of 0.01 to 20 mg-wt·cm/90° and a length of 100 mm.

These torsion suspensions have physical and mechanical properties which meet various requirements raised by modern electrical instrument-making techniques.

On the basis of experiments conducted by us we can recommend for high precision, vibration- and shockproof instruments with a large angle of twist, operating in tropical conditions or corrosive media, torsion suspensions types PtAg20 and Co40NiCrMoV, which are extremely strong, elastic and corrosionproof.

However, suspensions types PtAg20 cannot be used if a small thermal emf is required between it and copper, and those of type Co40NiCrMoV cannot be used when a high electrical conductivity is required.

In electrostatic instruments where suspensions are heated up considerably by the capacitative current it is advisable to use beryllium torsion suspensions.

These suspensions cannot be used, however, in precision instruments, since they have a high elastic fatigue after twisting.

Torsion suspensions made of BrSnZn4-3 can be widely used in high precision instruments of the most varied types, provided they are not required to be very strong mechanically and highly resistant to oxidation and corrosion.

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COMPUTING TORSION SUSPENSIONS FOR MOVING PARTS OF ELECTRICAL MEASURING INSTRUMENTS

P. B. Usatin

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pp. 32-35, February, 1961

The basic design parameters of torsion suspensions consist of: properties of the material; length l, mm; cross section q, mm^2; the shape of cross section (it can be evaluated numerically by a dimensionless coefficient n which is equal to the ratio of the cross-sectional area to the square of thickness); force P, g-wt exercised by the initial tensioning of the suspensions during assembly, and the elasticity of springs c, mm/kg-wt, which characterizes the bending of the spring under a unit tensioning force.

The main operational parameters of a torsion-suspended moving part consist of: its weight Q, g-wt; its relative restoring torque W, mg-wt · cm/90°; its deflection angle φ, degrees, the resistance of suspensions r, ohms; the permissible current density j, amp/mm^2; the natural frequency f_0 of the moving part mechanical vibrations in the directions perpendicular to the working displacement of the moving part; the instrument's grade of accuracy, which determines the permissible deviation γ_0 in its return to zero, errors γ_s due to the slope of the instrument, and its mechanical quality factor.

In engineering practice two design methods are employed: the use of graphs, nomograms and cables, and the use of design formulas. The two methods are complementary to each other.

Since the publication of GOST (All-Union State Standard) 9444-60 the design of torsion suspensions has been considerably simplified; however, the design engineer must use, in addition to the standard specification design, formulas both for cross checking and computing any required additional factors.

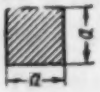
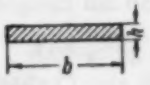
In this connection it is desirable to supplement GOST 9444-60 by data on the properties of the materials used in making the torsion suspensions [1], and to supply at least tentative data on the dimensions (width and thickness) of the torsion suspensions made of various materials and intended for various torques.

1. When the moving part is deflected by an angle φ, both torsion suspensions which connect the moving part to the stationary components of the instrument are twisted through an angle φ and develop a relative restoring torque W, mg-wt · cm/90° determined by the formula [2, 3]

$$W = 1.57 \cdot 10^5 \cdot \frac{q^2}{l}\left(\frac{k_1}{n}G + \frac{n}{12} \cdot \frac{P \cdot 10^{-3}}{q}\right), \quad (1)$$

where G is the second order modulus of elasticity (coefficient of rigidity) of the torsion suspension material, kg-wt/mm^2; k_1 is a coefficient depending on the shape of the cross section (Table 1).

TABLE 1

Shape of cross section	q	n	k_1	k_2	k_3
	$\frac{\pi}{4}d^2$	0.785	0.125	0.575	3.54
	a^2	1.0	0.141	0.675	4.0
	bh	$\frac{b}{h}$	$\frac{1}{3}-\frac{0.21}{n}$	$\frac{1}{\sqrt{n}}$	$\frac{2(n+1)}{\sqrt{n}}$

The first term of (1) represents the torque due to the tangential tension τ, which corresponds to pure twisting. The second term represents the torque due to normal stresses

$$\sigma_n = \frac{P \cdot 10^{-3}}{q}, \qquad (2)$$

which arise at the initial straining of the torsion suspension.

The tangential tensions are distributed in a non-uniform manner along the cross section of the torsion suspension [2]. For rectangular suspensions tangential tensions are absent in the corners of the cross section and attain their maximum value τ_{max} at two points of the outline in the middle of side b (Table 1). The value of the maximum tangential tension can be calculated from the formula

$$\tau_{max} = 1.75 \cdot 10^{-2} k_2 q^{0.5} \cdot G \cdot \frac{\varphi}{l}, \qquad (3)$$

where k_2 is the coefficient which depends on the shape of the cross section (Table 1).

For a rectangular section

$$k_2 q^{0.5} = h,$$

i.e.,

$$\tau_{max} = 1.75 \cdot 10^{-2} hG \cdot \frac{\varphi}{l}. \qquad (3a)$$

For a rectangular cross section the maximum tangential tension is proportional to the thickness of the suspension and does not depend on its width.

Example. The moving part is assembled with two torsion suspensions made of tin-zinc bronze (G = 4500 kg-wt/mm^2) with a cross section of 0.2 · 0.02 mm^2, a length of 15 mm and an initial tension of 100 g-wt. The full deflection angle of the moving part is 60°. It is required to determine the restoring torque M and the tension in the material (n = 0.2/0.02 = 10; k_1 = 0.312; k_2 = 0.316; q = 4 · 10^{-3} mm^2; P = 0.1 kg-wt).

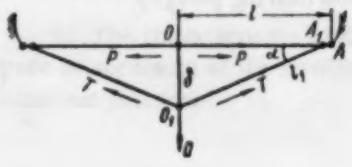
The relative restoring torque of one torsion suspension (as specified by GOST 9444-60) 100 mm long is

$$W_0 = 1.57 \cdot 10^5 \frac{(4 \cdot 10^{-3})^3}{100} \cdot \left(\frac{0.312}{10} 4.5 \cdot 10^3 + \right.$$
$$\left. + \frac{10}{12} \cdot \frac{0.1}{4 \cdot 10^{-3}} \right) = 0.025 (140 + 20.8) =$$

$$= 4 \text{ mg-wt} \cdot \text{cm}/90° \cdot 100 \text{ mm}.$$

The relative restoring torque of one torsion suspension of the given length is

$$W = W_0 \cdot \frac{100}{15} = 26.7 \text{ mg-wt} \cdot \text{cm}/90°.$$



The restoring torque of the moving part (for a full deflection angle) is

$$M = 2W \frac{\varphi}{90} = \frac{2 \cdot 26.7 \cdot 60}{90} = 35.5 \text{ mg-wt} \cdot \text{cm}.$$

The normal stress in tensioning (2) is

$$\sigma_n = \frac{0.1}{4 \cdot 10^{-3}} = 25 \text{ kg-wt}/\text{mm}^2.$$

The largest tangential stress (3a) is

$$\tau_{max} = 1.75 \cdot 10^{-2} \cdot 0.02 \cdot 4.5 \cdot 10^3 \cdot \frac{60}{15} = 6.3 \text{ kg-wt/mm}^2.$$

In the above example the maximum tangential stress amounts to 25% of the normal stress. If the length of the suspension be taken as l = 8 mm and its deflection angle as $\varphi = 240°$, the restoring torque will amount to M = 268 mg-wt · cm/90°, and τ_{max} = 47 kg-wt/mm², i.e., the tangential stress will be almost twice its normal value.

2. For moving parts with horizontal torsion suspensions the computation of the sag δ is very important and can be obtained from the equivalent circuit shown in the figure (p. 131). The two suspensions are assumed to be of equal length and the weight of the moving part concentrated at one point where the two suspensions join.

Let us denote the length of the suspensions when strained by force P (length $\overline{AO}$) by l. Owing to the weight of the moving part Q the suspension is under tension T equal to

$$T = \frac{0.5Q}{\sin\alpha} \approx 0.5Q \cdot \frac{l}{\delta}.$$

The length of the suspension corresponding to this tension is

$$\overline{A_1O_1} = l_1 = l \frac{1 + \frac{T}{qE} \cdot 10^{-3}}{1 + \frac{P}{qE} \cdot 10^{-3}} \approx l\left(1 + \frac{T-P}{qE} \cdot 10^{-3}\right),$$

whence

$$\frac{l_1 - l}{l} = \frac{T-P}{qE} \cdot 10^{-3},$$

where E is the modulus of elasticity of the suspension.

The additional sag of the spring under weight Q is

$$\overline{AA_1} = c\,(T-P) \cdot 10^{-3} = a.$$

Let us now determine the value of the sag from triangle A_1OO_1:

$$\delta^2 = l_1^2 - (l-a)^2 \approx 2l\,(l_1 - l + a);$$

$$0.5\frac{\delta^2}{l^2} = \frac{l_1 - l}{l} + \frac{a}{l} = \frac{T-P}{qE} \cdot 10^{-3} + \frac{c\,(T-P)}{l} \cdot 10^{-3}$$

Hence,

$$\frac{\delta^3}{l^3} = 10^{-3}\left(Q - 2P\frac{\delta}{l}\right)\left(\frac{1}{qE} + \frac{c}{l}\right). \tag{4}$$

In normally assembled instruments the relative sag should not exceed (5-10) · 10^{-3}. The elasticity of the springs is determined by c, which is of the order of 10 mm/kg-wt, thus making the value of c/l of the order of unity. These figures make it possible to calculate δ from a simplified formula

$$\delta \approx \frac{0.5Q}{P} l. \tag{4a}$$

Assuming that $\delta/l \leq (0.005\text{-}0.01)$, we obtain that $P \geq (50\text{-}100)\,Q$, i.e., that the initial tension of the suspensions must be about 100 times greater than the weight of the moving part.

The sag also determines the natural frequency of mechanical vibrations of the moving part [4]:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} \approx \frac{16}{\sqrt{\delta}}, \tag{5}$$

where g is the acceleration due to gravitation, mm/sec².

If δ = 0.04 mm, then f_0 = 80 cps. If the value of the sag is increased to 0.1 mm the natural frequency drops to 50 cps.

Let us transform (5) by means of (4a):

$$f_0 = 22.5\sqrt{\frac{P}{Ql}}. \tag{5a}$$

The natural frequency of oscillations rises with an increased tension, a decreased weight of the moving part and shorter suspensions.

3. The continuous permissible current in amperes is represented by formula

$$I^2 = \frac{1}{\rho} k_3 q^{1.5} P', \tag{6}$$

where ρ is the resistivity of the suspension, ohm · mm²/m; P' is the power per unit surface of the suspension, mw/mm²; k_3 is the coefficient depending on the shape of the suspension cross section (Table 1).

Formula (6) was derived on the basis of thermal calculations of the current flowing through the suspension, assuming that all the energy produced by the current is dissipated into the ambient medium through the side surfaces. In view of the very small ratio of the cross section to the length of the suspension, it is possible in these calculations to neglect the heat dissipation at the ends of the suspension.

According to experimental data [1] the specific power P' depends on the material from which the suspension is made (Table 2).

TABLE 2

Material of torsion suspensions	Specific power P', mw/mm²
BrSnZn4-3	0.9
Co40NiCrMoV	1.1
BrBe2	1.7
PtAg20	2.1

The values of the permissible specific power given in Table 2 can be increased [1] by a factor of 1.5-2 for suspensions with small cross sections (with a relative torque of $W_0 \leq 2$ mg-wt · cm/90° · 100 mm).

Example. Determine the permissible current for a torsion suspension made of tin-zinc bronze with a ratio of b/h = n = 10 and a relative torque of W_0 = 4 mg-wt·cm/90° · 100 mm. Since GOST 9444-60 does not specify suspension cross sections, we shall calculate the cross section on the basis of the breaking effort $q\sigma_t$ and tensile strength σ_t of the material.

$$\text{Cross section } q = \frac{q\sigma_t}{\sigma_t} = \frac{450 \cdot 10^{-3}}{115} = 3.9 \cdot 10^{-3} \text{ mm}^2.$$

Resistivity ρ = 0.09 ohm · mm²/m.

For n = 10 the coefficient $k_3 = 2 \cdot 11/\sqrt{10} = 6.95$.

$$I^2 = \frac{1}{0.09} \cdot 6.95\ (3.9 \cdot 10^{-3})^{1.5} \cdot 0.9 = 170 \cdot 10^{-4} \text{ amp}^2;$$

I = 0.13 amp.

Current density $j = I/q = 0.13/3.9 \cdot 10^{-3} = 33$ amp/mm².

In addition to the value of the continuous current, it is also necessary to determine the transient current overload specified by standards and specifications for measuring instruments which the torsion suspension can withstand. At present the "Vibrator" Plant has not sufficient experimental data for calculating the heating-up time constant and the temperature rise in the suspension for instantaneous overloads.

4. The characteristics of the moving parts on torsion suspensions which determine the metrological properties (grade of accuracy) of the instrument consist of the deviation in returning to zero and the error due to a slope in the instrument position.

The deviation in returning to zero depends [5] on time t that the moving part is kept in a deflected position, on the maximum tangential stress τ_{max} (3a), and on the distance of the extreme fibres from the center of the cross section, i.e., on the width b of the suspension.

The deviation in returning to zero for rectangular suspensions is

$$\gamma_0 = C_1 h \frac{\varphi}{l} b (1 - e^{-mt}). \tag{7}$$

By evaluating the deviation in returning to zero according to GOST 9444-60 for a constant twisting time and considering that $hb = q$, we obtain

$$\gamma_0 = C_0 q \frac{\varphi}{l}, \tag{7a}$$

where C_0 is a coefficient of proportionality which depends to a certain extent on the elastic properties of the suspension.

The error due to the slant in the position of the instrument, with the remaining conditions unchanged, is proportional to the product of the sag and the weight of the moving part, and is inversely proportional to the restoring torque:

$$\gamma_s = C_2 \frac{Q\delta}{M}. \tag{8}$$

This relationship holds for the moving parts both of horizontal and vertical suspensions.

From (4a) we obtain

$$\gamma_s = C_3 \frac{Q^2 l}{PM}. \tag{8a}$$

The error due to the slant rises with an increasing length of the suspension and drops with a rising ratio of the tensioning force to the weight of the moving part.

5. The instrument becomes accurate if the deviation γ_0 in returning to zero and the error γ_s due to the slanting position of the instrument are small, and it becomes reliable if the suspensions are robust, i.e., if their initial stress σ_n is small.

The three above parameters γ_0, γ_s and σ_n, which determine the accuracy and reliability of the instrument with torsion suspensions, are interrelated. A decrease in one of them inevitably produces an increase in another. The general mechanical properties of an instrument with torsion suspensions can be characterized by a common criterion of accuracy and strength [6]:

$$A = \frac{C_3}{\gamma_0 \gamma_s \sigma_n}, \tag{9}$$

which we shall call the mechanical quality factor.

From (7a), (8a) and (2), and the relation $M/\varphi = W$, which is derived from the definition of the relative restoring torque, we find the quality factor of instruments with torsion suspensions

$$A = C_A \frac{W}{Q^2}, \tag{10}$$

where C_A is the coefficient of proportionality; W is the relative restoring torque; Q is the weight of the moving part.

The quality factor does not depend on the dimensions of the torsion suspensions, on their initial stressing, or on the deflection angle of the moving part.

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CHOOSING THE LENGTH OF TORSION SUSPENSIONS

S. M. Pigin

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pp. 36-38, February, 1961

The length of torsion suspensions determines a whole series of measuring instrument parameters, including the dimensions of the measuring mechanism, the tensile strength of the suspensions for a given restoring torque, the sag of the suspensions in the horizontal position, the natural frequency and vibrationproof properties, the stress due to twisting, electrical resistance, and accuracy in reproducing the restoring torque.

The length of the two suspensions is added to the height of the measuring mechanism, thus constituting an inherent part of the instrument's dimensions.

Since the restoring torque is inversely proportional to the length of the suspension, variations in the latter for a constant torque inevitably lead to changes in its rigidity, and hence affect the tensile strength Q of the suspension.

Figure 1 shows a family of curves characterizing the relation between the tensile strength Q and the length of the suspension for several set values of torque. It will be seen from these curves that shorter suspensions provide a smaller absolute tensile strength, although they are relatively stronger.

The reserve strength against single shocks referred to the weight of the moving part G_0 can be evaluated from the relationship

$$n \approx \frac{Q(1-K_s)}{G_0}, \tag{1}$$

where $K_s = P/Q$ is the torsion stress coefficient under the effect of force P.

If this strength is insufficient, it is necessary to use correctly selected stops for limiting the deviation of the moving part [1].

The sagging of the moving part in the horizontal position leads to a reduction in the gap between it and the fixed components of the instrument, and to an imbalance in its position. It is, therefore, necessary in designing the instruments to limit the sag to 0.05 mm.

For a given stressing $P = K_sQ$ and weight of the moving part G_0 the sag amounts to

$$f = \frac{lG_0}{2P} = \frac{G_0}{2K_s} \cdot \frac{l}{Q} \tag{2}$$

and for a constant weight G_0 and a stress coefficient K_s it is represented by Q/l.

The relation of this expression to the length for several set values of the restoring moment for normalized platinum-silver torsion suspensions is given in Fig. 2.

From the above relations it follows that a smaller sag of the moving part is attained with shorter suspensions, since the ratio Q/l rises with a decreasing length of the suspensions.

The behavior of the instrument under the effect of vibration depends to a great extent on the resonance (natural) frequency ω_0 of the moving part. In a general case the higher the natural frequency the wider is the vibration range in which the instrument can be safely used.

The effect of the length of suspension on the vibrationproof properties of the instrument (its resistance or insensitivity to vibration) is characterized by its natural angular frequency ω_0 and the parameters of the moving part:

$$\omega_0 = \sqrt{\frac{2K_s Q}{m_0 l}}. \qquad (3)$$

where m_0 is the mass of the moving part.

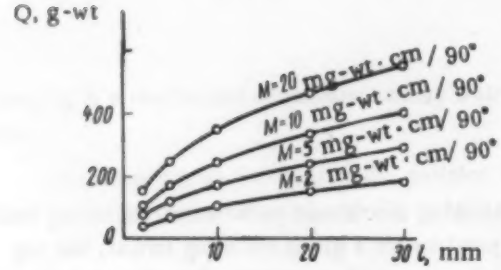

Fig. 1.

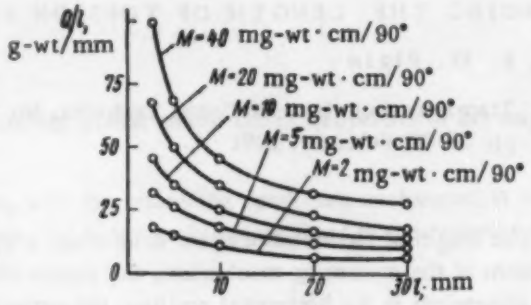

Fig. 2.

It was shown above that the ratio Q/l increases with a decreasing length of suspension, providing the restoring torque remains the same. For instance, if M = 40 mg-wt · cm/90°, a change in the suspension length from 30 mm to 5 mm will raise the natural frequency up to $\omega_0' = \omega_0 \sqrt{69/26.5} = 1.6\,\omega_0$, i.e., more than 1.5 times, providing the remaining conditions do not alter.

Thus for vibrating conditions one should aim to reduce the length of suspensions.

It was shown in [2] that the elastic fatigue β of the suspensions which are deflected through an angle α can be represented by expression

$$\beta = k\frac{bh}{l^2}\alpha t^n = k\frac{mh^2}{l^2}\alpha t^n = \frac{Ah^2}{l^2},$$

where k, n are experimental coefficients depending on the material; m = b/h; b, h are the width and thickness of the suspension; t is the decay time.

TABLE 1

	Length of the suspension, mm					
	2.5	5	10	15	20	30
Specified deviation in returning to zero, %	–	–	0.05-0.08	–	–	–
Actual deviation in returning to zero, %	0.45-0.75	0.15-0.25	0.05-0.08	0.028-0.045	0.018-0.03	0.01-0.016
Possible grade of instrument:						
PtAg20 torsion suspension	2.5-4.0	1.0-1.5	0.2-0.5	0.10-0.2	0.05-0.1	0.05-0.1
BrSnZn4-3	5.0	1.5	0.5	0.2	0.1	0.1
BrBe2	10.0	2.5	1.0	0.5	0.2	0.2

If the effect of a decreasing area is taken into account, the deviation in returning to zero (for α = 90°) for platinum-silver suspensions will have with respect to their length the values given in Table 1.

It will be seen from Table 1 that platinum-silver suspensions 2,5 mm long can be used with 2.5 – 4.0 grade instruments, and suspensions 5 mm long with 1.0-1.5 grade instruments.

From the point of view of the accurate return to zero the use of platinum-silver suspensions less than 20 mm long is not advisable.

The possible grades of instruments using bronze suspensions type BrSnZn4-3 and BrBe2 are considerably lower.

The ratio of the actual stress σ_m in its twisted condition to its initial normal stress σ_0 can be evaluated in the following manner.

The maximum stress in a twisted suspension is

$$\sigma_m = \sqrt{\sigma_0^2 + 4\tau_m^2},$$

where the normal stress is

$$\sigma_0 = \frac{P}{S} = \frac{K_s Q}{mh^2},$$

and the maximum tangential stress in twisting is

$$\tau_m = \frac{Gk_1 q_2 \Theta}{k_2} h + \sigma_0 h \frac{m^2+1}{12k_2} q_2 \Theta =$$

$$= h\Theta \left(\frac{k_1}{k_2} q_2 G + \frac{q_2}{K_2} \cdot \frac{1+m^2}{12} \sigma_0 \right),$$

where $\Theta = \alpha/l$; G is the modulus of rigidity.

For standardized torsion suspensions m = 10, moreover, $k_1/k_2 \approx 1$; $q_2 \approx {}^3/_4$ and $k_2 \approx {}^1/_3$.

Taking into account the value of these coefficients we obtain the torsional stress

$$\tau_m = h \left(\frac{3}{4} G + \frac{9}{4} \cdot \frac{1+10^2}{12} \sigma_0 \right) \Theta = h \left(\frac{3}{4} G + 19\sigma_0 \right) \Theta.$$

The ratio of the maximum stress to the initial normal stress σ_0 will amount to

$$\frac{\sigma_m}{\sigma_0} = \frac{\sqrt{\sigma_0^2 + 4\tau_m^2}}{\sigma_0} = \sqrt{1 + 4h^2 \left(\frac{3G}{4\sigma_0} + 19 \right)^2 \Theta^2}.$$

By substituting under the radical the value of $\sigma_0 = K_s \sigma_t$, where σ_t is the temporary tensile strength, we shall obtain

$$\frac{\sigma_m}{\sigma_0} = \sqrt{1 + h^2 \left(\frac{3}{2} \cdot \frac{G}{K_s \sigma_t} + 38 \right)^2 \Theta^2}. \qquad (4)$$

For a given material and stress the value of $\frac{3}{2} \cdot \frac{G}{K_s \sigma_t}$ is constant, and for the alloys used in the experiment, it is shown in Table 2 (according to the data of the laboratory directed by Z. A. Timofeeva).

The calculation of additional efforts was made up to twist angles of 360° or a stress coefficient of $K_s = 0.42$ (alloy PtAg20). Since for the above alloy it is permissible to have $K_s = 0.7$, all the cases in which the stress increment $\Delta\sigma \geq 0.66$ will indicate an impossible condition for the operation of this torsion suspension.

Such inadmissible conditions for $\Delta\sigma$ are shown in Table 3. Here the stress on the suspension will be 25-30% below the limit of proportionality σ_p.

For other coefficients K_s' the data for $\Delta\sigma$ can be approximately recalculated (for permissible values of $\Delta\sigma$) from

$$\Delta\sigma' = \Delta\sigma \left(\frac{K_{s\,av}}{K'_s} \right)^2.$$

TABLE 2

Alloy	$K_s = \sigma_p/\sigma_t$	$K_{s_{av}}$	σ_p, kg-wt/mm²	σ_t, kg-wt/mm²	G, kg-wt/mm²	$\frac{3}{2}\frac{G}{K_{s_{av}}\sigma_t}$	$K_{s_{perm}}$
BrSnZn4-3	0.65	0.30	80	115	$4.5 \cdot 10^3$	195	0.50
BrBe2	0.60	0.27	100	160	$5 \cdot 10^3$	175	0.45
PtAg20	0.9	0.42	160	200	$7 \cdot 10^3$	125	0.70
Co40NiCrMoV	0.75	0.35	190	300	$8 \cdot 10^3$	115	0.60

TABLE 3

Length of suspension	Excessive deviation angles for an instrument torque of, mg-wt · cm/90°			
	10	20	50	100
2.5	over 150°	over 110°	over 90°	about 90°
5	" 260°	" 200°	" 160°	over 135°
10	" 360°	" 360°	" 290°	" 260°
15	" 360°	" 360°	" 360°	" 330°
20	" 360°	" 360°	" 360°	" 360°

TABLE 4

l, mm	2.5	5	10	15	20	30
$\gamma_x = \frac{\Delta x}{l}$, %	16	8	4	2.7	2	1.3

Moreover, it is necessary that

$$K'_s (1 + \Delta\sigma') \leq K_{s_{perm}}. \qquad (5)$$

In order to evaluate the stress increment for other materials, the data for $\Delta\sigma$ can be approximately recalculated from formula

$$\Delta\sigma' = \Delta\sigma \frac{\left(\frac{3}{2} \cdot \frac{G}{K'_{s_{av}} \sigma'_t} + 38\right)^3}{\left(\frac{3}{2} \cdot \frac{G}{K_{s_{av}} \sigma_t} + 38\right)^3}.$$

Thus, for BrSnZn4-3 (Table 2) torsion suspensions we have

$$\Delta\sigma' = \Delta\sigma \left(\frac{195+38}{125+38}\right)^3 \approx 2.0\,\Delta\sigma,$$

for BrBe2

$$\Delta\sigma' = \Delta\sigma \left(\frac{175+38}{125+38}\right)^3 \approx 1.7\,\Delta\sigma,$$

and for Co40NiCrMoV

$$\Delta\sigma' = \Delta\sigma\left(\frac{115+38}{125+38}\right)^2 \approx 0.88\Delta\sigma.$$

From the above data the advantages of platinum-silver suspensions become obvious, especially for instruments with large deflection angles.

In particular cases it is necessary to calculate $\Delta\sigma = (\sigma_m/\sigma_0) - 1$ from (4) and evaluate its admissibility from (5).

A reduction in the length of the suspension of a given cross section decreases its resistance.

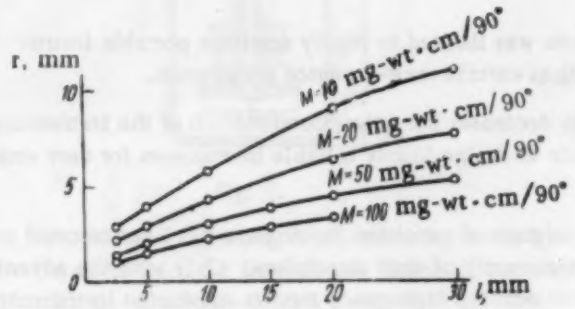

Fig. 3.

The relation of the resistance to the length of (two) suspensions for a constant restoring torque is shown in Fig. 3. Since for a constant restoring torque the cross section varies at a slower rate than the length of the suspension, its resistance grows with an increasing length.

Hence, short suspensions are in this case preferable to long ones.

The computed lengths of suspensions will be adhered to only approximately when the instruments are assembled. The dimensional estimate will include tolerances for various measuring mechanism components, such as the frame height or the length of the axis $\Delta x_1 \approx 0.06$ mm, the height of the suspension holder $\Delta x_2 \approx 0.3$ mm, the height of the ring $\Delta x_3 \approx 0.1$ mm, the height of the external bushing $\Delta x_4 \approx 0.1$ mm, the dispersion in the rigidity of the damping spring $\Delta x_5 \approx 0.15$ mm, the error in fixing the ends of the suspensions $\Delta x_6 \approx 0.2$ mm, thus making the total tolerance $\Delta x = \sqrt{\Sigma(\Delta x_n)^2} = 0.4$ mm^2.

The values of the relative probable error γ_x in adhering to the length of the suspension for $\Delta x = 0.4$ are given in Table 4.

Conclusions. The above makes it possible to note that there is no optimum length for torsion suspensions. For a number of parameters (overall dimensions, sagging, vibrationproof properties, electrical resistance), it is advisable to decrease the length; for other parameters (strength, failure to return to zero, stress due to twisting, accuracy in reproducing the torque), it is advantageous to have longer suspensions.

In particular cases the possibility of using a suspension of a certain length can be easily checked by simple calculations, and the actual conditions of its application will indicate which are the controlling factors.

In general it should be noted that the most suitable lengths for suspensions are in the range of 5-20 mm; moreover, the shorter suspensions should be used in rack-mounted instruments and the longer ones in laboratory instruments of increased and high grades of accuracy. For superminiature instruments (with a deflection angle up to 90°) even shorter suspensions of 2.5-3 mm may be used. The use of suspensions longer than 20 mm is not advisable.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

HIGH-PRECISION MOVING-COIL LABORATORY INSTRUMENTS WITH TORSION SUSPENSIONS

Yu. K. Obram and Z. V. Grigor'eva

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 39-42, February, 1961

Until recently the use of torsion suspensions in dc instruments was limited to highly sensitive portable instruments of a medium accuracy and portable galvanometers, as well as certain rack-mounted instruments.

The fixing of the moving part on torsion suspensions sharply decreases the power consumption of the instrument and practically eliminates bearing friction, thus making it possible to design highly reliable instruments for very small currents and voltages.

Despite the obvious advantages of torsion suspension, the designers of precision instruments have not resorted to this method owing to a certain conservatism, and partly to the short supply of such suspensions. Only with the advent of new alloys for the suspensions did it become possible recently to develop high-grade torsion-suspension instruments. In developing high-grade instruments the designers at present are resorting increasingly to torsion suspensions made of such alloys as platinum and silver, cobalt with nickel and chrome, and others. Suspensions made with these alloys have a very small elastic fatigue of the order of 0.02-0.03% and a small temperature coefficient (less than 1% per 10°C). Moreover, they are very strong: their tensile breaking stress goes up to 250 kg-wt/mm^2.

However, all these qualities of the new suspensions are insufficient for the design of high-grade instruments. It is necessary both to change the construction of the instruments to suit these suspensions and to modify the technology of production, especially with respect to the ageing of units and components.

By way of example let us examine the construction of measuring mechanisms on torsion suspensions for grade 0.2 and 0.1 instruments made at the "Vibrator" Plant.

The measuring mechanism of a grade 0.2 instrument (Fig. 1) has a magnet inside the coil frame made in the shape of a parallelepiped out of a magnico alloy with an admixture of titanium. The magnet is compressed into a ring consisting of pole pieces with filled-in brass spacers. The magnet with its pole pieces is in turn placed inside a silumin yoke; on the outside the magnet is surrounded by an armco ring.

Such a closed and symmetrical system provides good protection from external magnetic fields and has a small stray inductance. The suspensions are fixed to the frame in such a way as to ensure a constant centering and exclude the possibility of the suspension becoming displaced by mechanical effects, which in turn provides stable balancing (Fig. 2). In this construction the suspension is taken over a roller, which is pressed into a bushing, and is secured by a wedge with the suspension's free end soldered to a terminal. The other end of the suspension is soldered to a damping spring of original construction (Fig. 3), which provides the required tension. Extensive experience in the use of various types of springs has led us to the conclusion that the spring of the above construction is suitable for high-grade instruments.

This construction provides a large sag (1.5 mm) in a constant direction with good centering. The length of each suspension is 20 mm, thus decreasing sufficiently the effect of the elastic fatigue. The tube-shaped limiter restricts the displacement of the moving part by mechanical effects both in the axial and radial directions. The moving coil is wound on a frame which, in conjunction with appropriate ageing, provides sufficiently stable dimensions and shape of the coil for a long time. The deflection angle of the moving part is about 90°. For indication a glass pointer 97 mm long is used, moving over a 150 mm scale.

The current consumed by the measuring mechanism is 0.5 ma and is controlled by a magnetic shunt. The pointer is set to zero by a correction device. The weight of the moving part is 0.8 g; the torque of the suspension is 0.8 $\frac{\text{mg-wt}\cdot\text{cm}/90^\circ}{100\ \text{mm}}$ the balance coefficient is 10; the magnetic induction in the gap is 1500 gauss.

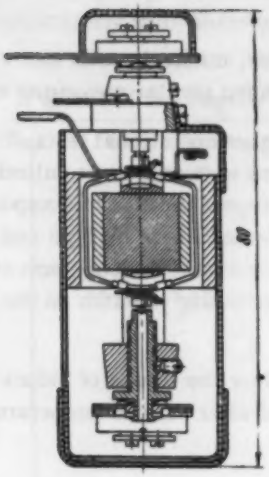


Fig. 1.

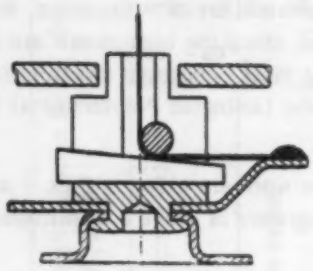


Fig. 2.

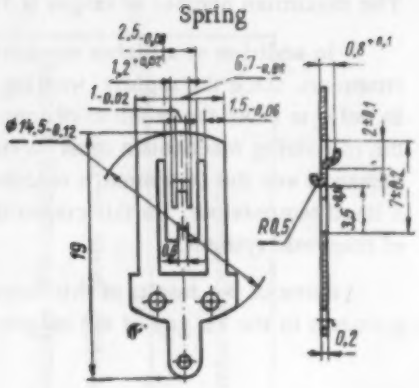


Fig. 3.

The measuring mechanism is installed in the casing and covered by lids which protect it from impurities, as well as from the flow of air, during adjustment. The mechanism dimensions are 50 × 25 × 80 mm, and its weight is 50 g – as compared with its counterpart in instruments M104-M106, which has dimensions of 100 × 100 × 50 mm and weighs over 1 kg.

The measuring mechanism of a grade 0.1 instrument has an external magnet with an armco ring-shaped yoke 70 mm in diameter. The magnets are made of an alnico alloy which, according to A. V. Mitkevich's investigations, provides a greater stability for a longer time.

Microscopic changes in the dimensions of the frame will only affect certain secondary errors (friction, tilting) in pivoted instruments, whereas similar changes will affect the basic error in torsion suspension instruments. For such instruments the cast frame is replaced by a brass one, which is cut and milled. Such a frame after appropriate ageing possesses highly stable dimensions. The fixing of the suspensions and damping springs is the same as in grade 0.2 instruments. The length of each suspension is also 20 mm. The construction of 0.1 grade instruments does not allow the use of tube-shaped limiters employed in grade 0.2 instruments, and therefore laminated limiters are used. As in grade 0.2 instruments, the moving coil of this instrument is wound on a frame of alloy AMG-5, which is particularly rigid.

The instrument uses a luminous display with a repeated reflection of the beam and two light indicators obtained by means of a double-faced moving mirror. The scale is made accordingly in two lines of a conical shape with a total length of 300 mm. The length of the beam is 270 mm, the angle of rotation of the moving part about 40°, the full-scale current is 0.5 ma controlled by a magnetic shunt in the range of ± 2-3%; the pointer is adjusted to zero by means of a correcting device with a micrometer screw. The weight of the moving part is 0.9 g, the torque of the suspensions is $2\frac{\text{mg-wt}\cdot\text{cm}/90^\circ}{100\text{ mm}}$, the balance coefficient is 22, and the magnetic induction in the air gap is 2000 gauss.

The measuring mechanism is made in the form of a completely sealed unit. It is covered on top and bottom with plastic lids. In the lower lid an ordinary glass window is fitted for the passage of the beam. The upper lid carries a device for coupling to the corrector. Both lids, with packing, are fixed to the magnet. The overall dimensions of the unit are 90 × 70 × 70 mm, and its weight is 460 g.

The above characteristics of the measuring mechanisms have made it possible to design grade 0.2 and 0.1 instruments whose properties are considerably better than those of existing models. The lower current consumption of the measuring mechanisms, amounting to 0.5 ma as against 1.5 ma in type M104-M106 instruments, has made it possible to bring down the lower current limit to 0.75 ma (in instruments types M104-M106 it is 15 ma) and the current consumption of voltmeters to 1 ma as against 3 ma in instruments types M104-M106. The maximum measured current is 30 amp in grade 0.2 instruments and 15 amp in grade 0.1 instruments; maximum voltage for the 0.2 grade is 750 v, and for 0.1 grade, 600 v.

Instruments of the 0.2 grade have 6 versions (M1104-M1109), with a maximum number of ranges in one version amounting to 29.

Instruments of the 0.1 grade are made in 3 versions (M1150-M1152)–ammeter, millivoltmeter and voltmeter. The maximum number of ranges is 14, in the ammeter version. All three versions have similar measuring mechanisms.

In addition to a higher sensitivity the use of torsion suspensions provides a higher operational reliability of instruments, since the rapidly wearing pivots are replaced by highly stable suspensions with an almost unlimited life. In order to solve the problem of long-term stability of instruments, the effect of temperature on the components of the measuring mechanism must be studied, since the instruments are inevitably affected in use by high and low temperatures and the instrument's reaction to these conditions characterizes to a certain extent its long-term stability at a fixed temperature. In this connection the Leningrad Polytechnical Institute is conducting research on the stability of magnetic systems.

Some of the results of this extensive work are given in Figs. 4 and 5, which show the results of induction measurements in the air gap of the magnetic systems of grade 0.2 instruments before and after various temperature effects.

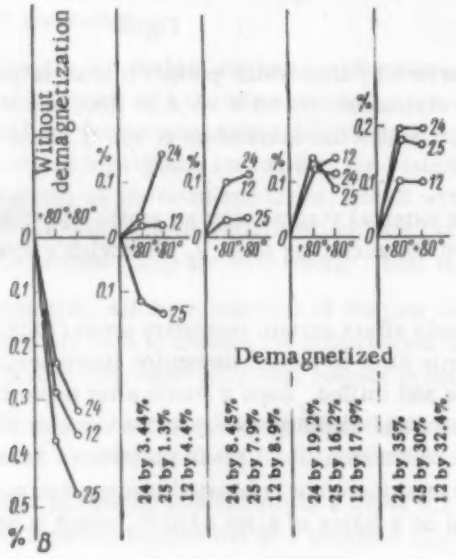


Fig. 4.

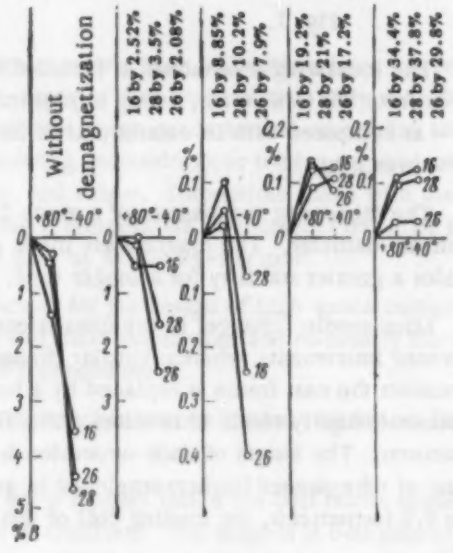


Fig. 5.

Measurements were made on a special magnetometer with an error not exceeding 0.01% of the measured value. It will be seen from Figs. 4 and 5 that magnetic systems which have not been demagnetized, or have been demagnetized by 1-4%, only react significantly as a rule to cooling down to -40°C, even if they were previously treated at a temperature of +80°C (Fig. 5). Their induction is reduced by as much as 5%. Heating up to +80°C affects only systems which have not been demagnetized. Systems which have been demagnetized by 16-22% and 30-38% maintain their inductance after cooling down to -40°C; in some of them the inductance rises by up to 0.1%.

In the course of testing it was discovered that the variation of magnetic induction in the air gap due to the temperature of -40°C depends not only on the degree of demagnetization, but also on the composition of the magnetic alloy. Thus, a number of grade 0.2 measuring mechanisms were subjected after demagnetization and stabilization at +80°C to the effect of a temperature of -40°C. As a result of this test 50% of measuring mechanisms with magnico alloy magnets exceeded the limits specified for grade 0.2 instruments (see table). When the same alloy was used with a 2% titanium aftercharge, far better results were obtained. Magnets are therefore being made at present of a magnico alloy with a 2% titanium aftercharge, and the magnetic systems of the measuring mechanisms are demagnetized in an alternating field by 10-20%.

It is known that the basic difficulties in providing a certain accuracy for an instrument do not arise in its manufacture, but in ensuring that the instrument retains its grade of accuracy during a more or less long period. In order to attain the required stability certain components and units are subjected to artificial and natural ageing. Moreover, finished instruments are subjected to natural ageing. For grade 0.2 it lasts 15 days; for grade 0.1, 70 days.

It is equally important to make the instrument insensitive to external effects. Both instruments (grades 0.1 and 0.2) are sufficiently well protected by their design from various ferromagnetic effects.

Effect of the Degree of Demagnetization on the Error

Magnet alloy	Demagnetization by an alternating field, %	Change due to a temperature of −40°C		Percentage of measuring mechanisms which passed the tests	Number of instruments
		Maximum value, %	Mean value, %		
Magnico	2.5-5.4	-0.30	-0.23	0	3
"	8-10	-0.18	-0.08	57	7
"	12-20	-0.18	-0.07	63	8
Magnico +2% titanium (1st batch)	12-20	-0.03 +0.06	-0.02 +0.03	100	8
Same (2nd batch)	10-15	-0.05 +0.06	-0.03 +0.03	100	12

The temperature error is more difficult to deal with since it depends on the temperature error of the measuring mechanism and that of the circuit.

In the measuring mechanism the temperature variations affect the magnetic induction in the air gap and the elasticity modulus of the suspensions and springs (used for fixing the suspensions).

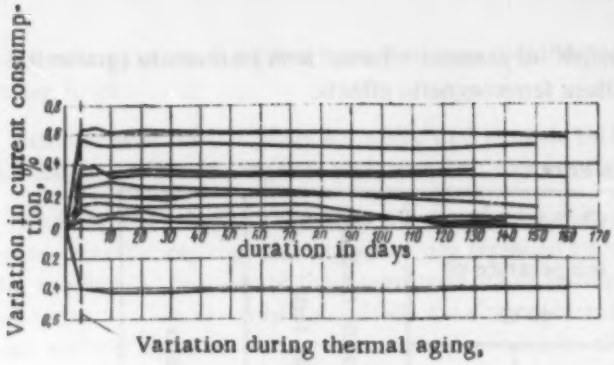
The temperature error of the circuit is caused by the copper frame and the suspensions whose resistance varies with temperature.

In order to compensate the temperature error grade 0.2 instruments include resistors type MMT-8 with a negative temperature coefficient, whose use makes it possible to raise the torque of the instrument and eliminate the labor-consuming work of selecting copper reels.

In compensating the temperature effect in grade 0.1 instruments it is impossible to neglect the temperature coefficient of the measuring mechanism, which amounts to 0.1%, and it has to be determined for each measuring mechanism. In this case it is impossible to compensate with thermistors, owing to the considerable dispersion in the value of the temperature coefficient. Therefore, the temperature effect of the copper frame, the suspensions and the measuring mechanism in grade 0.1 instruments is compensated by shunting the frame and part of the building-out resistor, by means of a resistance consisting of copper and manganin. This makes it possible to change within certain limits the temperature coefficient of the circuit by varying the components of this resistor without changing its total resistance. In this manner it is possible to compensate for various values of the measuring mechanism temperature coefficient without varying the nominal current through the mechanism.

In conclusion, it is necessary to dwell on certain practical results obtained from the tests of the measuring mechanisms.

The stability characteristic of grade 0.2 measuring mechanisms during cyclic and extended temperature ageing is shown in Fig. 6. The consumed current of the measuring mechanism is plotted along the Y-axis and the heat treatment along the X-axis up to the dotted line, beyond which the ageing of the measuring mechanisms with time is shown.



Variation during thermal aging, 3-6 cycles
Fig. 6.

It will be seen from Fig. 6 that during five months of extended ageing the consumption current of the measuring mechanisms changed by 0.12%, and thus the method adopted for artificial cyclic ageing is suitable for grade 0.2 instruments.

The preliminary test results of grade 0.1 instruments have shown the possibility of making instruments of this grade as well, provided the suggested technology of production and ageing is adhered to.

However, the efficiency of the above method of ageing for instruments of both grades can only be established after studying a sufficiently large number of instruments produced under normal conditions.

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THERMAL INSTRUMENTS ON TORSION SUSPENSIONS

V. I. Chervyakova

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 42-45, February, 1961

The production of laboratory thermal instruments at the "Vibrator" Plant is closely connected with the extended use of torsion suspensions.

In the first period, development was concentrated on instruments with individual measuring units with a luminous indicator, next on thermal instruments with a standardized miniature point-indicator on torsion suspensions, and finally on laboratory thermal instruments with dc photoamplifiers and an indicator with a vertical scale, i.e., with a horizontal moving part.

In the first period mass production was started on thermal milliammeters type T13 with a range of 1 ma to 3 amp, and thermal ammeters T12 with a range of 5-10 and 20 amp, for measurements over a wide frequency range.

The development and production of these devices have become possible owing to the use of microwire with glass insulation made by A. V. Ulitovskii's method. This wire has also opened the way to the mass production of highly sensitive vacuum contactless thermal converters with nominal currents of 1 ma and higher, and to research and development of air contactless thermal converters with a reduced error due to skin effect and also the development and putting into production at the plant of highly sensitive moving-coil instruments with torsion suspensions which can measure small emfs (from 2 to 12 mv) produced by the contactless thermal converters at their output.

Thermal instruments types T13 and T12 until recently were the only high-frequency instruments produced by our industry. The T13 milliammeters with a range of 1 to 3 ma have to date superior operational properties to similar instruments produced by well-known foreign firms.

However, our developing national economy required thermal instruments of even higher accuracy and wider frequency range. In this connection our plant started the necessary development work and also extended the types and reduced costs of production of thermal instruments.

The accuracy of thermal instruments is mainly determined by that of the moving coil measuring device; hence priority was given to the development of improved devices of this type, standardized for all the thermal instruments.

In the first period of the development of torsion-suspension instruments the moving parts of thermal instruments could not be made of a grade higher than 1.0 with an operating length of the suspension not less than 15 mm, using a luminous indicator. In the T13 instrument the light beam had to be reflected several times. Thus, the dimensions of instruments T12 and T13 were large. The optical arrangements and auxiliary supply source for the luminous indicator made the instrument more expensive and more difficult to assemble. Moreover, owing to the large size of the measuring unit the total capacitance of the instrument relative to the ground was increased, thus worsening its operational properties.

The successful work carried out by the plant in developing new alloys for the torsion suspensions, and in particular platinum-silver suspensions, and the accumulated experience in developing and manufacturing torsion-suspension devices have made it possible to design and start production of miniature grade 0.5 pointer moving-coil instruments.

In order to extend the frequency range of the existing thermal instruments and increase their assortment, work has been conducted on the improvement and design of new high-quality attachments. Some of the thermal converters and thermal milliammeters were redesigned, and new materials were used in the production of air contactless thermal converters. In conjunction with scientific research institutes high-frequency ferrite cores have been produced and tested. The investigation of various types of ferrites has made it possible to develop current transformers covering a wide frequency range.

During the development of thermal voltmeters, research was initiated on high-frequency, permanently stable multiplying resistors.

All this has made it possible to develop and put into production in a short time five new improved types of laboratory thermal instruments with a standardized, miniature, grade 0.5 pointer meter on torsion suspensions. The new thermal instruments include a thermal milliammeter grade 1.0 with a range up to 100 Mc, thermal ammeters with high-frequency current transformers, and thermal voltmeters grade 1.5 with a range up to 30-40 Mc.

The basic technical parameters of these instruments are given in the table.

Type of instrument	Top measuring limits	Grade of accuracy	Type of current	Frequency range, cps	
				nominal	extended
Thermal ammeters type T14	4; 6; 10; 15; 25; 40 and 60 amp	4	~	$5 \cdot 10^3$ - $(5-30) \cdot 10^6$	–
Thermal milliammeters type T15/1	5 ma	1.0	≅	$20-25 \cdot 10^6$	$75 \cdot 10^6$
	10 ma			$20-25 \cdot 10^6$	$70 \cdot 10^6$
Thermal milliammeters type T15	30; 50 ma	1.0	≅	$20-20 \cdot 10^6$	$70 \cdot 10^6$
	100 ma			$20-20 \cdot 10^6$	$60 \cdot 10^6$
	300 ma			$20-10 \cdot 10^6$	$30 \cdot 10^6$
Thermal voltmeters type T16	0.75; 1.5; 3 v	1.5	≅	$20-20 \cdot 10^6$	$40 \cdot 10^6$
	7.5; 15; 30 v			$20-15 \cdot 10^6$	$30 \cdot 10^6$
Thermal ammeters type T18	0.5; 1; 2.5; 5; 10; 15; 25 amp	1.5	≅	$50-2 \cdot 10^6$	$5 \cdot 10^6$
	50 amp			$50-1 \cdot 10^6$	$2 \cdot 10^6$

For current measurement at 100 Mc the error of these instruments does not exceed ±4% of the full scale reading.

It is characteristic of all the new thermal instruments that their meters have graduated numbered linear scales. The readout in the units of the measured variable is obtained by means of a conversion scale (Fig. 1). The conversion

scale is attached to any given high-frequency converter and consists of four scales arranged in two lines with top and bottom numbering. The lower part of each scale has uniform divisions and is used for setting the slider against the graduation corresponding to the reading of the meter. The upper markings are used for the readout in units of the measured variable.

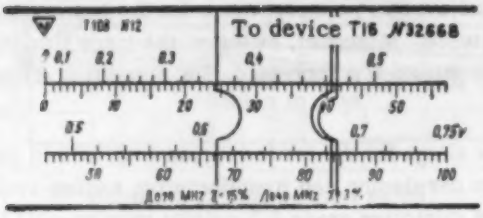

Fig. 1.

The conversion scale is placed on the face of the external screen of the meter and can be easily replaced.

The conversion scale facilitates the replacement of thermal converters when they burn out, makes the production of a set of thermal converters for a single instrument possible, and makes it easier to produce interchangeable meters. Thus, the manufacture of the new standardized meter on torsion suspensions with a conversion device has made it possible to develop a series of different thermal instruments which differ only in the technical characteristics of their meters and their high-frequency attachments, connected to the meter through an external screen by means of a plug and a screened cable.

In all these instruments the measuring circuit is separated from the high-frequency circuit and is connected to it either by a capacitative (contactless thermal converter) or an inductive (current transformer) coupling, thus improving the operational characteristics of the instrument.

The new thermal ammeter type T14 has a completely screened high-frequency current transformer type I104 with an external working gap in order to prevent any capacitative coupling between the measuring circuit and the primary lead, which carries the high-frequency current. The working range of the current transformer is 5 kc to 30 Mc.

The appearance of transformer I104 resembles that of the T1105 type transformer, but its quality differs considerably from that of the latter. The use of a new high-frequency insulation material has made it possible to operate the current transformer in high-tension circuits with a 5 kv potential to earth. The replacement of the expensive thin permalloy tape by ferrite cores has made the transformer considerably cheaper without affecting its frequency range. The production technology of the transformer has been developed in such a way that the adjustment and calibration of the instrument can be made at 50 cps and only the completed thermal ammeters need be checked at the lowest frequency of the range, i.e., at 5 kc, where the greatest measurement error is to be expected.

The new thermal milliammeters T15 and T15/1 possess a higher accuracy and a wider frequency range.

The high-frequency part of the milliammeter consists of a vacuum contactless thermal converter TVB enclosed in a polystyrene shell. In this construction the shunting capacitance has been greatly decreased, which accounts in the main for the extension of the range up to 100 Mc.

The frequency errors of the thermal milliammeters T15 and T15/1 with respect to their ranges are given in Fig. 2.

The thermal milliammeter coils are matched both with respect to the consumed current and to the voltage, which makes them interchangeable. Several thermal converters for different ranges can be ordered for one meter.

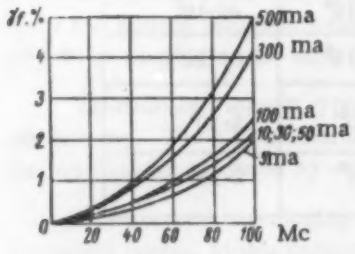

Fig. 2.

The new series of thermal instruments includes voltmeters which have been developed and mass-produced for the first time in the Soviet Union.

The high-frequency attachment to the thermal voltmeter T16 consists of a vacuum thermal converter TVB-2 and a multiplier wire-wound resistor BLP which are mounted inside a metallic shell.

In order to reduce the input capacitance of the thermal voltmeter the insulation between the input and the ground terminal is made of "Kel-F".

The thermal voltmeter is supplied with a set of measuring heads for various ranges and is designed to measure in unbalanced circuits at dc and in the range of 20 cps to 30-40 Mc. The current consumption of the instrument is 3 ma.

Experimental models of thermal voltmeter T16 have passed their state tests and it is at present being mass-produced.

According to the conclusions arrived at after state testing the basic parameters of thermal voltmeters T16 (input impedance, current consumption and frequency range) are better than those of foreign thermal voltmeters of the same grade and dimensions.

The new series of thermal instruments also includes a thermal ammeter T18 with separate thermal converters T109, T110 and T111. Thermal ammeter T18 is supplied with an air contactless thermal converter, with a range of 0.5 to 50 amp. The thermal converters for 2.5 amp and higher have their heaters made of thin-walled tubes. The T18 instruments can be used for measuring the current at the grounding point of a circuit, and are widely used in the radio-electronic industry for testing high-frequency cables, and as reference meters in checking current transformers in the range from a few kilocycles up to 1 Mc.

Among the thermal instruments developed and produced at the plant the multirange thermal voltmeter T17 deserves special attention. The development and production of a multirange thermal voltmeter with the lowest range of 75 mv became possible only after mastering the production of highly sensitive dc photoamplifiers, which use a galvanometer with new high-quality torsion suspensions.

It is known that the sphere of application of thermocouple instruments is limited by their low overload capacity, and in the case of a voltmeter by their low input resistance.

The thermal voltmeter T17 uses a normal vacuum contactless 1 ma thermal converter in conjunction with a photocompensated amplifier, which has a lower measuring limit of 40 μv. Owing to this combination it has been possible to reduce the current flowing through the thermal converter heater to one-tenth of its former value. Thus, in retaining all the advantages of normal thermocouple devices, this instrument has acquired new qualities, such as a high input resistance of 10 kohm/v and a higher overload capacity. This voltmeter can withstand long overloads of twice its maximum reading and short overloads ten times that reading. Its schematic is shown in Fig. 3.

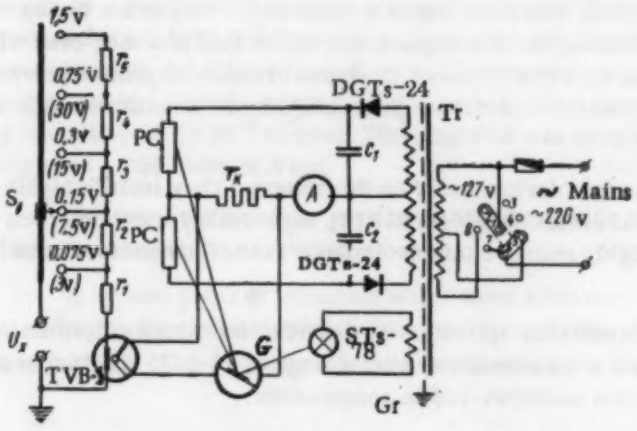

Fig. 3.

Readings are obtained from a pointer microammeter with torsion suspensions, which is connected to the output of the photocompensated amplifier.

The thermal voltmeters are made in the ranges of 75-150-300-750-1500 mv or 3-7.5-15-30 v. The grade of accuracy is 1.5, and their current consumption 100 μa. They can be used for dc and ac measurements in the range of 20 cps to 1 Mc and are widely employed in measuring frequency characteristics of various electronic tubes and other devices.

Our tests have shown that thermal voltmeters T17 can also work at frequencies below 20 cps, and with certain modifications in the design of the vacuum thermal converters they can also be used at infrasonic frequencies.

The development and production of thermal voltmeter T17 are only the first step toward the production of thermal instruments of higher sensitivity and higher overload capacity. The further modernization of photoamplifiers, the development of new, more compact amplifiers, and the experience acquired by the plant in making torsion-suspension instruments with horizontal moving parts, have made it possible to develop in 1960 a new series of highly sensitive laboratory thermal instruments of four types: T130, T131, T132 and T133.

Instruments T131 and T132 are modernized versions of thermal voltmeter T17 with the same measuring ranges.

Instrument T130 is a multirange millivoltmeter with a small input resistance (current consumption of 2.5 ma) but with a measuring limit of 30 mv. Instrument T133 is a multirange thermal microammeter with ranges of 100-250-500-1000 μa.

For convenience of use these instruments have a vertically placed scale and in their external appearance will form a series of unified highly sensitive photocompensated dc instruments developed and put into production by the plant.

Any further progress in the development of highly accurate instruments with a wide frequency range depends mainly on improvements in vacuum contactless thermal converters, whose parameter stability and frequency characteristics require considerable improvement.

PHOTOCOMPENSATED AMPLIFIERS WITH TORSION-SUSPENSION GALVANOMETERS

S. G. Rabinovich

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 46-48, February, 1961

Photocompensated amplifiers [1] provide at present, it would appear, the most effective combination of a high voltage sensitivity with a minimum power consumption from the measured circuit, as well as the possibility of recording the readings or using the small measured signals for control purposes.

It is known that the output current of the amplifier can serve as a measure of the input voltage, and the measurement results are almost independent of the parameters of the electron tube, illuminating lamp, photocells, and the supply conditions. However, the above valuable properties of the amplifiers only hold with control galvanometers which have a sufficiently small torque.

Galvanometers on pivots always have a friction torque. Since the angles through which they rotate during operation are extremely small (tenths, hundredths and even thousandths of a degree), the torque thus produced even with relatively rigid torsion suspensions is considerably smaller than that produced in pivots. Torsion-suspension galvanometers are, therefore, used in preference to any others in sensitive, accurate photocompensated amplifiers which have been developed and produced by our plant in recent years.

At present our industry produces over 10 types of various devices based on this system. They include highly productive semiautomatic potentiometers R2 [2], universal deviation bridges R19 [3], high-quality stabilized rectifiers U1136 and U1199 [4], precision comparators F13, highly sensitive microvoltmeters F116, fluxmeters, thermal instruments, etc.

In order to illustrate the efficiency of the photocompensation system let us examine, for instance, instrument F116 (Fig. 1). Since the amplifier is designed to work into a microammeter with a range of 25-0-75 μa, it does not require any electron tubes and employs only one differential cadmium-sulfite photovaristor.

Fig. 1.

The instrument has 18 ranges: from 1.5 μv to 0.75 mv and from 0.15 to 75 μa in the first version, and from 0.015 to 7.5 μa and from 150 μv to 75 mv in the second version. In the most voltage-sensitive range the instrument graduations amount to $2 \cdot 10^{-8}$ v. Damping time (including the output microammeter) does not exceed 4 sec. Its error amounts to 4% in the most sensitive range and 1.5% on other ranges.

In evaluating instrument F116 it should be noted that its voltage sensitivity is equal or even superior to that of the best types of mirror galvanometers. However, for equal deflections (75mm) the galvanometers use at least $2 \cdot 10^{-13}$ w as compared with the $5 \cdot 10^{-15}$ w consumed by this amplifier. Moreover, mirror galvanometers have a considerably larger damping time and require periodic calibration.

It should be noted that F116 instruments do not exhaust the possibility of raising the sensitivity of photocompensated systems.

Moving-coil galvanometers are used in F116 instruments as in other photocompensated amplifiers made at our plant.

In view of the decisive effect of the controlling galvanometer on the operation of the photocompensated instrument, let us examine in detail its characteristics, construction and behavior.

One of the peculiarities of a photocompensated galvanometer consists in its operation over very small deflection angles, which prevents the beam from leaving the surface of the photocells, but requires a strict limitation of its movement. The moving part has, therefore, a special tongue 1 (Fig. 2) which rotates between four stops. The stops are adjusted in such a manner that tongue 1 simultaneously rests against stops 3 and 4 or stops 2 and 5.

This simple device is necessary, since if it only had two stops (for instance, 2 and 3), the moving part during overloading would rest against one of them only, and by acquiring a torque with respect to the stop could be displaced from its axis of rotation, bending out its suspensions. A construction with four stops eliminates this effect.

The restriction of the turning angle to 2-3° makes it possible to use in such galvanometers torsion suspensions with a much larger width-to-thickness ratio than normal. This circumstance provides either a greater strength of suspension or a lower restoring torque.

However, the use of torsion-suspension galvanometers in photocompensating amplifiers makes them rather shock-sensitive. Although they operate quite satisfactorily on ordinary tables and benches under laboratory, workshop and even field conditions, and only the most sensitive models require to be mounted on wall brackets, nevertheless their tendency to be shock-sensitive limits the use of photocompensated instruments and constitutes their disadvantage.

Special research has been conducted at the plant in order to determine the pattern of the galvanometer shock-sensitivity and find methods of eliminating it.*

These investigations were carried out on a photocompensated amplifier type F16 [1]. The disturbance was produced by a calibrated impact of a brass ball against the body of the galvanometer. For this purpose a 20 g ball suspended from a 1500 mm thread was displaced from a vertical position by a known angle and released. In its movement it struck the side surface of the galvanometer casing. The galvanometer was set into a position to be normally just in contact with the vertically hanging ball. The instrument was tested in a shorted condition set to a range with a sensitivity of $2 \cdot 10^{-8}$ v/mm. The amplifier was overdamped (the degree of damping was about 3) and had a damping time of the order of 3 sec.

The transient processes were recorded on recorder N16 with an undamped oscillation period of $T_0 = 0.25$ sec in its optimum damping condition.

A typical graph of transients which arose after such shocks is shown in Fig. 3. It will be seen from the graph that despite the overdamped galvanometer these shocks produce slowly decaying torsional self-oscillations of its moving part. The frequency of these oscillations approaches that of the natural torsional oscillations of the galvano-

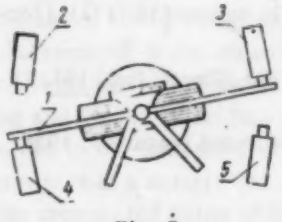

Fig. 2.

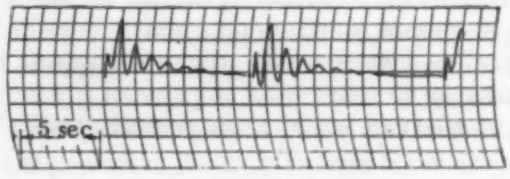

Fig. 3.

meter, but does not coincide with it. The natural oscillation period of the galvanometer amounts to 2 sec, but the period of the self-oscillations amounts to 1 sec, as will be seen from the oscillogram in Fig. 3.

It should be noted that the above low-frequency self-oscillations decay very slowly. It will be seen from Fig. 3 that the process lasts over 5 sec.

*The galvanometer's sensitivity to shock was investigated by the author in conjunction with A. N. Kasperovich. G. P. Kantor and P. A. Kovalev participated in this work.

The effect of the moving part balance on the above process was also investigated. The oscillogram in Fig. 3 was obtained with the galvanometer in a carefully balanced position. A galvanometer slant of 5° produced a rotation of the moving part through less than 0.06° with suspensions 17 mm long and a stiffness of 0.056 mg-wt · cm/90° for a length of 100 mm.

It was found that even with an imbalance 20 times worse than the above the transient process produced by the impact did not differ, as far as one could observe, from that shown in Fig. 3. It should be noted, however, that when the imbalance of the moving part exceeds a certain level the galvanometer's sensitivity to shocks increases rapidly.

An increased tensioning of the suspension, as would be expected from the data provided in literature [5, 6], decreases considerably the instrument's sensitivity to shocks. In the last experiment it was found that the frequency of self-oscillations is almost independent of the tensioning of suspensions, and is proportional to the square root of the restoring torque.

The mechanism which produces the low-frequency oscillations due to shock is not completely clear. On the basis of the experiments carried out it was assumed that these oscillations are related to the transverse vibrations of the galvanometer's moving part and to the difference in the stiffness of normal ribbon suspensions in various directions. This is confirmed, among other things, by the fact that these oscillations depend on the relative position of the planes of the upper and lower suspension, and by the fact that the torsional self-oscillations were very small with suspensions which had a circular cross section.

The above assumption is also supported by the fact that galvanometers with liquid dampers of transverse oscillations [7] were not subject to torsional self-oscillations. The above experimental data refer to photocompensation amplifier galvanometers. But they also hold for any torsion-suspension galvanometers.

Conclusions. The above investigations have shown that in order to decrease drastically the galvanometer's sensitivity to shock it is necessary to suppress or prevent transverse oscillations of its moving part. This can be achieved by the use of transverse oscillation dampers.

Magnetic induction dampers, for instance, can be used. Transverse oscillations occur almost exclusively in the direction of the least stiffness of suspensions, thus facilitating the design of magnetic induction dampers.

However, liquid dampers seem to be more promising. Such damping can be achieved either by immersing the whole moving part in a liquid, or by means of concentrated drop dampers [7]. Preliminary experiments have shown the great efficiency of liquid dampers. It would appear that the use of such dampers in the control galvanometers of photocompensated systems will make it possible to use these instruments under the most difficult operating conditions.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

THE USE OF TORSION SUSPENSIONS IN VIBRATION- AND SHOCKPROOF INSTRUMENTS

I. I. Rozenbaum and S. I. Yur'eva

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pp. 48-51, February, 1961

Side by side with the extended application of torsion suspensions in the instruments made at the "Vibrator" Plant, attention has been paid to improvement in the shock- and vibrationproof properties of these instruments, and in particular of photoamplifier galvanometers and oscilloscope loops, as well as to the production of rack-mounted circular-scale instruments. The present article deals with the latter problem.

Rack-mounted circular-scale instruments have a moving part rotating in the horizontal plane, and therefore requiring short, highly-tensioned suspensions in order to obtain a small sag in the moving part, which is necessary for its balancing during assembly.

Experience with pivot instruments has shown that the greatest difficulty encountered in effecting their shock-proof operation consists in the design of the moving part; this condition fully applies to torsion-suspended instruments also.

The shockproof properties of all the units and components of a torsion-suspension instrument including its moving part are attained by the same means as those of the corresponding components of a pivot instrument. It is only the suspensions themselves and their tensioning springs that require special treatment in order to protect them from snapping or breaking.

We carried out experiments under the following conditions:

Jolting was tested by shocks with an acceleration up to 70 m/sec^2 and a frequency of 80 to 120 shocks per minute, with the testing lasting 6 hours. Vibrations were tested on a standard two-directional vibration table in the range of 3 to 33.3 cps with amplitudes of 0.3 to 0.9 mm and corresponding accelerations of 0.4 to 38 m/sec^2. The tests lasted 6 hours. Shocks were tested on an impact machine with a freely falling load by means of 6 impacts of maximum intensity.

The suspensions were tensioned to 250 g-wt and had a length of 8-10 mm which provided a calculated sag of 0.04 mm.

Numerous experiments have shown that the breaking of suspensions under shocks is due to two causes.

The first cause is the lag in the displacement under shock of the moving part as compared with the external ends of the suspensions, fixed to components which move with the body of the instrument.

The lagging of the moving part puts an additional stress on the suspensions (on either one or both, depending on the direction of the impact), thus providing additional strains. If the sum of these additional strains and those due to the initial stressing of the suspension exceeds its elastic strength, it will snap. It will be easily seen that components which limit the radial and axial displacement of the moving part (Fig. 1) will protect the suspensions from overloading and prevent their breaking. For this purpose it is only necessary to select correctly the limiter air gaps so that the rise in the tensioning of the suspensions due to the displacement of the moving part by the amount of the gap does not exceed a certain value, which is smaller than the difference between the tensile strength of the suspension and the preselected value of its tensioning. Thus, the value of the gap depends on the weight of the moving part, the stiffness of the tensioning springs, and the strength and length of the suspensions.

Experience has shown, however, that the use of limiters decreases considerably the number of broken suspensions but does not entirely eliminate the breaking. Further experiments and observations of the torsion-suspension instruments produced at the plant have helped to discover the second reason for the breaking. It consists in the so-called "return" impact of the tensioning springs.

The above phenomenon is due to the vibration of the tensioning spring when it is unbalanced. These vibrations about its balanced position are asymmetrical, since the balanced position corresponds to an equilibrium in a tensioned position of the suspensions and not a free position of the springs. At the beginning of the inward movement of the

spring in the direction of the moving system, the spring is affected by the force of initial tensioning, the inertia of the moving part proportional to its weight, and the inertia of the moving portion of the spring itself proportional to its referred weight. All these forces are counterbalanced by the stiffness of the spring.

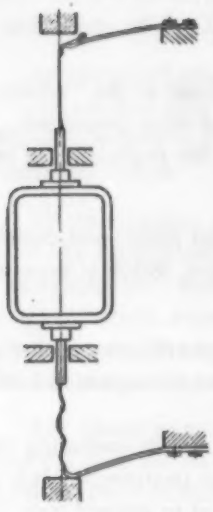

Fig. 1.

When the moving part of the instrument, the torsion suspension, and the spring which are moving together cover a distance equal to the limiter gap, the moving part will be stopped, but the spring will continue its movement and increase the sagging of the suspension. Since the weight of the tensioning spring is considerably less than that of the instrument's moving part and incomparably less than the force of initial tensioning, the movement by inertia of the end of the spring after the stopping of the instrument's moving part by the limiter will be stopped very soon by the counteracting force of the spring stiffness, which will initiate a reversed outward movement. At the beginning of the outward movement of the end of the spring only its tensile force will act in that direction, and the counteracting force will only appear when the sagging of the suspension is taken up. This counteracting force will grow more rapidly when the end of the spring passes through the unloaded spring's point of equilibrium. Thus the end of the spring will acquire a considerable velocity and a corresponding kinetic energy. The amplitude of the outward movement with respect to the unloaded spring's equilibrium position will be considerably larger than that of the inward movement, which is restricted in any direction by the displacement of the moving system in the limiter gaps, which in practice amount to 0.2-0.3 mm.

The reversed impact of the spring consists in the kinetic energy of the outward moving tensioning spring being absorbed by a sharply rising tensioning of the suspension fixed to the moving system, whose displacement has been stopped by the limiter. It is precisely this phenomenon which is the cause of the breaking of suspensions in instruments which only have limiters of the displacement of their moving systems.

As soon as additional limiters of the outward spring movement were added, the snapping of the springs was eliminated.

The necessity to provide the required strength for the moving part of a shockproof circular-scale instrument raises the weight of that part up to 2.5-3.5 g, which requires in an instrument with a horizontal moving part a high tensioning of the suspensions in order to keep the sagging within permissible limits. It was, therefore, necessary to use very strong platinum-silver alloy suspensions, which possess good tensile properties.

The requirement to reduce to a minimum the rise in the tensioning of suspensions as a result of the displacement of the moving system within the limits provided by the limiter gaps—whose dimensions were dictated by design and production considerations—made it necessary to provide tensioning springs sufficiently elastic to develop large efforts. The production of such springs from normal materials used for this purpose was found to be difficult, since these springs became cumbersome and their dimensions did not correspond to the remaining components, which made the instrument assembly difficult and led to an undesirable increase in its dimensions. These difficulties were overcome through the use of beryllium bronze for the tensioning springs.

The use of platinum-silver alloy suspensions and beryllium bronze springs provided an additional advantage because of their high thermal stability, since it became possible to fix securely the ends of the suspensions by soldering them with normal tin solder, thus almost completely overcoming the difficulties encountered in the fixing of suspensions.

In order to ensure high vibrationproof properties it is necessary, in general, to adopt the same measures as for shockproofing. It should, however, be noted that instrument components under vibration conditions are subjected to periodic accelerations over relatively long time intervals. These accelerations are considerably smaller than those due to shocks but their repetition frequency and the duration of their effect are much larger. Moreover, the accelerations and corresponding deformations of components may rise very sharply if the natural frequencies of the components under consideration correspond to the excitation frequency.

Experience has shown that immunity from vibrations of these instruments can be completely ensured providing these considerations are taken into account.

It was found more difficult to make the instruments vibrationproof, i.e., insensitive to vibrations.

Here we came across entirely new phenomena which did not exist in pivot instruments.

Torsion-suspended instruments exhibited under vibration two tendencies. The first consisted of a random oscillation of the pointer over the whole scale from one stop to the other, the second of a drift, the displacement of the pointer away from the place on the scale corresponding to the measured value.

Normally the drift was accompanied by oscillations of the pointer about the drift position. These oscillations were sometimes accompanied by a sudden jump of the pointer to a new drift position, sometimes followed after an interval by random oscillations of the pointer over the whole scale, once more followed by a drift position, etc.

We assumed that the main reason both for the drift and the oscillations of the pointer consisted of rapidly repeated impacts of the instrument's moving part against a component which limited its displacement (Fig. 2). A technique was developed for verifying this assumption and a series of experiments carried out which confirmed our theory.

The test equipment consisted of the standard two-directional vibration table, mentioned at the beginning of the article, and a model of the instrument's moving part, on torsion suspensions with exchangeable components, placed on it (Fig. 3). The model consisted of a base with two supports carrying bushes with tensioning springs. One of the supports could be displaced along the base and fixed in any required position. On the inside of the supports

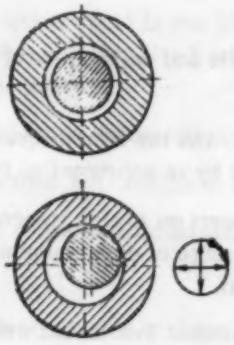

Fig. 2.

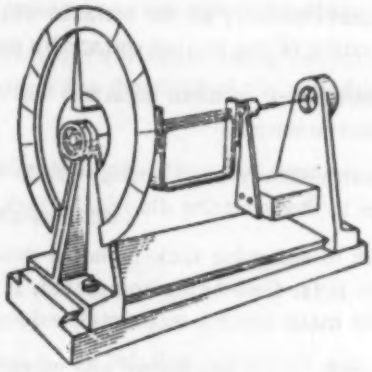

Fig. 3.

the exchangeable limiters of the moving system's displacement were mounted on insulated pads. A scale was mounted on the outer side of a support for the purpose of noting the deviation angles of the pointer, which was fixed to the moving system. During the operation of the vibration table the model displayed the same characteristics as other instruments with torsion-suspended moving systems, namely, drifting, oscillations of the needle, etc.

Next a simple electrical circuit consisting of a current source and a milliammeter was connected at one end to the system's movement limiters, which were all electrically interconnected, and at the other end to the torsion suspensions and their holders, also interconnected electrically. There was no current flowing through this circuit, since the limiters were electrically insulated from the stand and the components of the moving system. Neither was there any current when the vibrating table oscillated at a low rate (less than 3 cps), but at this rate there was no drifting or other phenomena characteristic of torsion-suspension instruments under vibrating conditions. When the frequency was raised to 6-7 cps drifting appeared and simultaneously the milliammeter indicated current pulses.

The repetition of this experiment under different conditions (by changing the air gap in the limiters, the weight of the model's moving system, the tensioning of the suspensions, etc.) invariably produced the same result: when drifting and other phenomena characteristic of torsion-suspension instruments appeared under vibration conditions, the milliammeter registered current pulses, which indicated an impact of the moving system against the fixed details of the instrument, in our case against the limiters of the moving system's movement.

To make the instrument vibrationproof it was necessary - while preserving the limitation of the moving system's displacement, which is required in order to make it withstand shocks and shaking - at the same time to prevent its impact against other fixed components.

This requirement was satisfied by filling the gaps in the limiters with polysiloxen liquid. This measure was based on the following considerations. It will be seen from Fig. 2 that in a two-directional vibration, impact between the torsion-suspended frame and the limiters is inevitable. This impact generates two forces, the force of inertia of the moving part applied to the center of its mass which lies on the axis of rotation of the latter, and the force of impact or the force of friction (depending on the nature of the impact) applied at the circumference of the suspension holder, always in the opposite direction to the force of inertia.

The torque of this couple, amounting to the product of one of these forces by the distance between them, equal to the radius of the suspension holder, is the main reason for the characteristic vibrations of the torsion-suspension instruments.

The filling of the gap with a viscous liquid produces a double effect. In the first place this liquid prevents the suspension holder from touching the limiter with an increasing force as the layer gets thinner. Secondly, the resistance to the displacement of the moving part does not produce a torque, since the force of this resistance is always applied to the whole of the torsion suspension circumference, i.e., it is symmetrical to the rotation axis of the system. It has already been shown that the inertia tending to displace the moving part lies on its axis of rotation with a precision determined by the balancing accuracy of the moving part.

Polysiloxen was chosen for filling the gaps because it hardly evaporates at all and because its viscosity depends relatively little on temperature over a wide temperature range. Since this liquid easily wets the surface of the majority of materials used in instrument-making, it is necessary, in order to prevent it from "running" all over the instrument, to treat carefully all the surfaces which limit the spreading of the liquid by one of the substances which prevent the wetting of the treated surface by polysiloxen.

The effectiveness of these measures was checked both on a model sample and on samples of moving-coil and moving-iron instruments.

These instruments proved satisfactory in their electrical and shock tests, and the feared squirting of the liquid out of the gaps in shock testing did not, in fact, occur. The limiter gaps used by us amounted to 0.2-0.3 mm.

The work in designing rack-mounted shock- and vibrationproof instruments on torsion suspensions is continuing, and although it is far from being completed, it is possible even at its present stage of development to draw certain conclusions and make certain recommendations which, of course, are not final.

Conclusions. 1. A shockproof and vibrationproof circular-dial rack-mounted instrument with torsion suspensions can be designed for a sufficiently wide frequency range.

2. In producing such an instrument it is necessary to aim at a minimum weight for the moving part and maximum tensioning of the suspensions. Moreover, the natural frequencies of the instrument's components and units should be, as far as possible, outside the range of the vibration frequencies which may be encountered in the instrument's application.

3. The displacement of the instrument's moving part must be limited, and the limiter gaps should be made smaller than the effective gaps between any other components of the instrument and its moving parts under vibration conditions, taking into consideration the contraction of gaps under vibrations and the possibly accompanying resonance effects.

4. It is recommended that the limiter gaps be filled with polysiloxen liquid of medium viscosity, and all the surfaces limiting the spreading of polysiloxen should be carefully treated with a substance which prevents the wetting of the surface by the liquid.

5. The displacement of the damping springs in the direction away from the moving system should also be limited. Moreover, the gaps in these limiters should be smaller than the corresponding gaps in the limiters of the moving system's displacement in the same direction.

6. All these provisions are additional to and do not replace the measures normally taken in designing shockproof instruments for the purpose of damping the whole instrument or its measuring mechanism.

ERRORS IN THE COMPENSATION METHOD OF MEASURING PULSED VOLTAGES

M. M. Levin

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pp. 52-54, February, 1961

In recent years there has been a growing tendency to use compensation methods [1, 2, 3] for measuring pulsed voltages with a large duty factor.

The compensation method consists essentially of the following: the diode is fed by the measured pulses U (for video-pulses U is the maximum value, and for high-frequency pulses U is the amplitude). The value of the pulsed voltage across the diode load R depends both on U and on the negative bias E, which constitutes the compensating voltage. For a certain value of the pulse across the diode load the equality U = E will hold.

When the voltage across load R reaches the required value, a special indicating circuit is operated (normally it is a trigger circuit whose threshold of operation $\underline{v}$ is equal to the required voltage across the diode load).

The assumption made in the literature cited above that the diode has a definite anode current cutoff leads to the conclusion that equality U = E will be most accurate when the operation threshold of the indicating circuit is made as small as possible.

The actual diode characteristic, however, is represented by an exponential curve and does not possess a cutoff.

Let us examine the conditions for which U = E in an actual characteristic.

The diode characteristic equation is

$$i = Ae^{ku}. \tag{1}$$

If the indicator reacts to the total voltage across the diode load R, the relation between U and E at the instant of the indicator circuit operation will have the form

$$U = E + v + \frac{1}{k} \ln \frac{v}{AR} = E + U_L. \tag{2}$$

It will be seen from (2) that a decrease in $\underline{v}$ will not in general lead to a reduction in the absolute value of U_L. It also follows from (2) that the equality U = E is met when

$$AR = ve^{kv}. \tag{3}$$

When the indicator reacts only to the positive portion of the pulse across the load the relation between the measured and compensating voltages has the form

$$U = E + v + \frac{1}{k} \ln \left(\frac{v}{AR} + e^{-kE} \right). \tag{4}$$

It will be seen from (4) that the relation between U and E in this case becomes nonlinear. However, when large voltages are measured, we have $v/AR \gg e^{-kE}$ and (4) is transformed into (2), and when (3) is fulfilled, U = E. In the latter case U is equal to E with the relative error of

$$\delta = \frac{U - E}{U} \approx \frac{1}{kEe^{kE}}. \tag{5}$$

For k = 10 1/v and U > 0.7 v, $\delta < 0.5\%$.

It will be seen from (2) that the determination of $\underline{v}$ with a relative error of γ_v produces a relative measurement error of

$$\delta_v = \frac{v}{U}\gamma_v + \frac{1}{kU}\ln(1+\gamma_v). \quad (6)$$

The determination of AR with a relative error of γ_{AR} produces a relative measurement error of

$$\delta_{AR} = -\frac{1}{kU}\ln(1+\gamma_{AR}). \quad (7)$$

Let us now examine the error in measuring the amplitude of high-frequency pulses. Let us assume that the diode load is shunted with a capacitance and there is no high-frequency voltage across it, and that the indicator reacts to a total voltage across the load.

At the instant of the indicator circuit operation the following equation holds:

$$ve^{kv} = ARI_0(kU)\,e^{-kE}, \quad (8)$$

where I_0 (kU) is a modified zero order Bessel function.

If it is taken into consideration that for large voltages I_0 (kU) $\approx e^{kU}/\sqrt{2\pi kU}$, it is possible to show that, in measuring high-frequency pulses, the value of U will be most accurately equal to E when

$$ve^{kv} = \frac{AR}{\sqrt{2\pi}}. \quad (9)$$

This will involve an error of

$$\delta = \frac{U-E}{U} = \frac{\ln kU}{2kU}. \quad (10)$$

It can be shown that if the indicator reacts only to the positive portion of the pulse across the load the error will be

$$\delta = \frac{\ln kU}{2kU} + \frac{1}{kUe^{kv}\sqrt{2\pi}}. \quad (11)$$

The error in determining $\underline{v}$ and R has the same effect as in the case of the measurement of video pulses. From equations (3) and (9) it is possible to choose optimum relations between $\underline{v}$, R and A.

The use of an indicator which reacts to the complete voltage provides a smaller error when small voltages are measured than that provided by an indicator which reacts only to the positive portion of the pulse.

The presence of the transfer capacitance C_d of diode D and of the capacitance C_L which shunts the load (Fig. 1) leads in measuring video pulses to a condition of equality of U = E differing from that given in (3), thus resulting in an additional error produced by transient processes.

Since a transient process in a circuit with an exponential diode cannot be easily computed, we shall linearize the diode characteristic. In linearizing it we shall consider that the diode current between pulses is equal to zero. The diode operates on the part of the characteristic between -E and -v (for U = E). The linearized characteristic will be represented by a straight line passing through the points of the characteristic corresponding to voltages -E and -v (Fig. 2).

Such a characteristic is possessed by an element consisting of a resistor R_d connected in series with emf $E_{eq} = -E$.

Since E and E_{eq} cancel each other, the equivalent circuit will have the form shown in Fig. 3.

Since R_d depends on E the measuring process can be regarded as an adjustment of the resistance by measurement of R_d in order to provide the required voltage $\underline{v}$ across resistor R for any measured input voltage.

If the voltmeter is fed by a trapezoidal pulse, then at the end of its leading edge T_{le} the relative variation in the voltage across the load will be, as compared with that obtained without the capacitances, equal to

$$\gamma_{le} = \frac{(C_d R_d - C_L R)\,R_d}{T_{le}(R_d+R)}\left(1-e^{-\frac{T_{le}}{\tau}}\right), \quad (12)$$

where $\tau = (C_d + C_L)\frac{R_d R}{R_d + R}$.

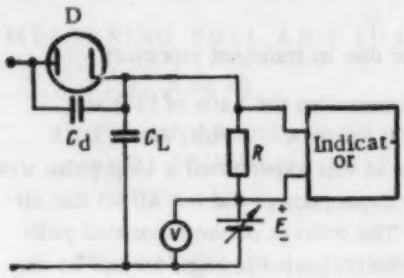

Fig. 1.

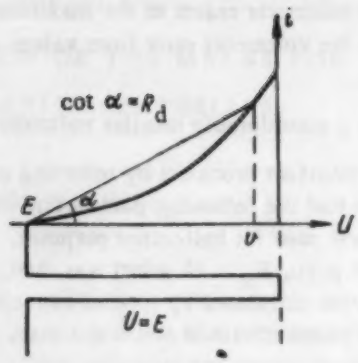

Fig. 2.

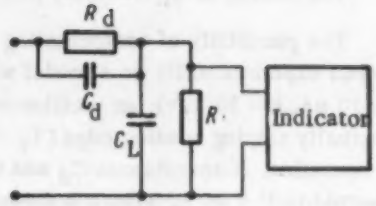

Fig. 3.

Thus, γ_{le} will rise with a decreasing T_{le} and increasing τ.

For $T_{le}/\tau \ll 1$, i.e., for a sharply rising leading edge we have

$$\gamma_{le\,max} = \frac{C_d R_d - C_L R}{R(C_d + C_L)}. \tag{13}$$

It will be seen from (12) and (13) that for $C_dR_d > C_LR$ we have $\gamma_{le} > 0$, i.e., we have a "direct transmission" of the pulse through the diode, and the voltage across the load is higher than it would have been without the capacitances in the circuit. For $C_dR_d < C_LR$ we have $\gamma_{le} < 0$, i.e., the voltage across the load is smaller than it would have been without any capacitances in the circuit.

For $C_dR_d = C_LR$ we have $\gamma_{le} = 0$, and the voltage across the load is equal to what it would have been without any capacitors in the circuit.

By representing the compensation voltmeter circuit as a potential divider, we can express R_d in terms of the measured voltage:

$$R_d = \frac{U-v}{v} R. \tag{14}$$

Substituting (14) into (12) and (13) we obtain

$$\gamma_{le} = \frac{R_d}{T_{le}} \left(C_d \frac{U-v}{U} - C_L \frac{v}{U} \right) \left(1 - e^{-\frac{T_{le}}{\tau}} \right) \tag{15}$$

and

$$\gamma_{le\,max} = \frac{C_d}{C_d + C_L} \cdot \frac{U}{v} - 1. \tag{16}$$

From (15) we obtain the condition for which $\gamma_{le} = 0$:

$$\frac{C_L}{C_d} = \frac{U}{v} - 1. \tag{17}$$

Since R_d depends on U, the condition for which $\gamma_{le} = 0$ will also depend on U.

By the end of the flat portion of the pulse, the voltage across the diode load will differ from what it would have been without any capacitances by the relative value of

$$\gamma_f = \gamma_{le} e^{-\frac{T_f}{\tau}}. \tag{18}$$

It will be seen from (18) that condition $\gamma_{le} = 0$ is at the same time a condition for $\gamma_f = 0$.

Figure 4 shows the shape of the pulse across the diode load.

Since the indicator of the slideback voltmeter reacts to the maximum instantaneous value of the voltage across the diode load, it is necessary to compute the voltmeter error from values of γ_{le} if $\gamma_{le} > 0$, and from the value γ_f if $\gamma_{le} < 0$, as will be seen from Fig. 4.

The choice of C_L from (17) provides a considerably smaller voltmeter error due to transient processes.

The possibility of compensating for transient processes by selecting capacitances on the basis of (17) was checked experimentally on a model which had the following parameters: R = 100 kohm, v = 1 volt, diode 2D1S (A = 10 μa, k = 10 1/v); an oscilloscope was used for indication purposes. Since in this experiment a long pulse with a gradually sloping leading edge (T_f = 140 μsec, T_{le} = 15 μsec) was used, stray capacitances did not affect the circuit operation. Capacitances C_d and C_L were simulated by special capacitors. The voltage of the measured pulse amounted to U = 10 v. Figure 5 shows the pulses obtained across the load. The oscillograms in Figs. 5a and 5c are

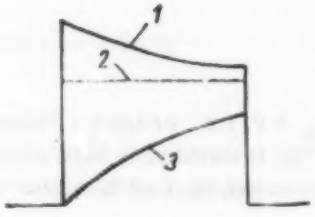

Fig. 4. The shape of the pulse across the diode load. 1) $C_dR_d > C_LR$, $\gamma_{le} > 0$, $\gamma_f > 0$; 2) $C_dR_d = C_LR$, $\gamma_{le} = 0$, $\gamma_f = 0$; 3) $C_dR_d < C_LR$, $\gamma_{le} < 0$, $\gamma_f < 0$.

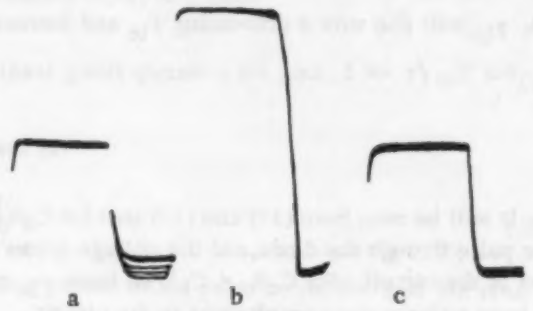

Fig. 5. Shape of the pulse across the load: a) with capacitors C_d and C_L disconnected; b) C_d = 1000 μμf and C_L = 4000 μμf, Eq. (17) is not fulfilled, $\gamma_{le} = 1$; c) C_d = 1000 μμf, C_L = 9000 μμf, Eq. (17) is fulfilled, $\gamma_{le} = 0$.

practically the same, thus indicating that, provided the conditions given in (17) are met, C_d and C_L do not affect the operation of the slideback voltmeter.

In the case when $\gamma_{le} \neq 0$, the slideback voltmeter error may be considered as an equivalent variation in the operating threshold voltage $\underline{v}$ of the indicator by the relative value of $-\gamma_{le}$ or $-\gamma_f$.

Thus the error due to the transient process can be calculated from (6).

Conclusions. 1) For correct operation of a slideback voltmeter which measures pulsed voltages, it is not necessary to aim at a minimum threshold operating voltage $\underline{v}$ of the indicator, but at a value of $\underline{v}$ which meets the requirements given in (3) or (9). Eqs. (3) and (9) do not provide separate values for $\underline{v}$ and R, but only determine the relation between them and the diode parameters A and $\underline{k}$. The choice of $\underline{v}$ and R is more or less arbitrary. One consideration for choosing R should consist in providing sufficient time for capacitance C_L to discharge between the pulses.

2. The measurement error due to the error or the instability of the indicator's threshold of operation or the diode load resistor can be computed from (6) and (7).

3. By choosing the load capacitance C_L by means of (17) it is possible to reduce the voltmeter error due to transient processes. Since the value of C_L in (17) depends on the measured voltage, it may be advisable to couple the adjustment of the compensating voltage E with that of capacitance C_L.

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MATERIAL RECEIVED BY THE EDITORIAL BOARD

INTENSIFIED STATE INSPECTION OF THE MEANS FOR MEASURING FUEL AND LUBRICATING MATERIALS

I. I. Kogan

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 55-56, February, 1961

The resolutions of the 21st CPSU (Communist Party of the Soviet Union) Congress provide for the rapid development of the oil industry, the wider use of oil for industrial and power-production purposes, and as raw material for the chemical industry. A considerable yearly increase in the production of oil will raise the amount of work involved in its transportation, storage, pumping, and measuring out of oil and oil products. Hence, one of the most important problems is the reduction of losses in fuel and lubricating materials during the execution of this work.

With this object in view the State Inspection Laboratories for Measurement Equipment of the Russian Federation are busily engaged in improving the means for measuring fuel and lubricating materials in the oil industry of the Republic. In the third quarter of 1960, in 17 regions, areas and autonomous republics with sizeable oil utilization, the means of measuring fuel and lubricating materials were checked, a large number of gauges, measuring instruments and tanks were inspected, the existence and condition of calibrating tables for tanks were verified, and the state of accountancy of oil products examined.

The laboratories forwarded the classified inspection results together with their proposals to the Sovnarkhozes (Councils of National Economy), and the regional and area Soviet Executive Committees, and the Councils of Ministers of the Autonomous Republics.

The head administration of the Committee of Standards, Measures and Measuring Instruments attached to the RSFSR (Russian Socialist Federated Soviet Republic) Council of Ministers summarized the test data and adopted the required measures for eliminating the defects thus revealed.

The inspection revealed that the oil industry is using a considerable number (19.3%) of defective measures and measuring instruments.

The measures and measuring instruments are in a particularly bad condition in the oil depots of the Glavneftesnab (Central Oil Supply Administration) of the Krasnoyarsk territory, the Rostov, Sakhalin and Kuibyshev regions and the Stavropol territory.

The check inspection established that many oil agencies receive and deliver oil and oil products in bucketfuls and tinfuls by ladling out or pouring the products out of them, etc., thus leading to an inaccurate estimate of the delivered fuel, and preventing an estimate of its losses.

The insufficient use made of oil flowmeters leads to a loss of fuel and to inaccurate accountancy, and facilitates abuses.

A considerable obstacle to reducing losses in oil and oil products consists in the absence of calibration charts or the use of inaccurate charts for tanks.

This explains why in the majority of cases when residues were measured large quantities of surplus fuel and lubricating materials were found.

Thus, in the Izobil'i oil depot of the Stavropol' territory the surplus quantities of gasoline amounted to 4223 kg, of diesel oil to 2133 kg; in pumping stations the gasoline surplus amounted to 8979 kg and that of diesel oil to 16,285 kg. In the South Sakhalin automobile depot in 15 working days 2000 kg gasoline was discovered in excess of the amount recorded in the account books. Other surpluses were discovered at the steel cable manufacturing plant (Stalingrad region) amounting to 33,000 kg, and at the Petrov plant amounting to 1046 kg of unaccounted for gasoline.

The surpluses of fuel and lubricating materials result from defects in the measuring-out systems, inaccurate measuring methods, incorrect accountancy, defective methods in estimating their density, and an insufficient quantity of measuring devices.

The normalized maximum oil consumption figures are obsolete, and the standards are excessive.

Considerable misunderstanding arises between the oilfields, the pipeline administration and the oil refining plants in determining the quantity of raw materials.

It is necessary to establish a unified standard, and to specify in a State Standard the methods of sampling oil products in tanks, since GOST (All-Union State Standard) 2517-60 does not provide these data. It is also necessary to increase the production of measuring instruments and automatic devices for measuring and issuing out fuel and lubricating materials.

The State Inspection Laboratories for Measuring Equipment have raised the question of improving the handling of fuel and lubricating materials in their reports to the Sovnarkhozes, regional and territory executive committees and the Councils of Ministers of the Autonomous Republics, and are striving to eliminate the above defects. Thus, at the initiative of the Kaliningrad GKL (State Inspection Laboratory), the regional committee passed a resolution instructing its subordinate administration to calibrate in a given time all their tanks, to mount them on level, fireproof foundations, paint them and number them, to repair faulty tanks, and to fit them with serviceable lids. In the same resolution the executive committee of the regional Soviet forbade all the organizations and enterprises to use substitute measures, and instructed the regional administration of the "Glavtorgmash" (central engineering trading organization) and the supply and sales administration to supply the appropriate enterprises and organizations with the measuring instruments they require. The regional local industry administration was charged with the task of organizing the production of measures and tank calibration tables in centimeter steps to be supplied to all the regional organizations.

The central technical information bureau of the Altai Sovnarkhoz is drawing up instructions for keeping records of and measuring fuel and lubricating materials.

The Murmansk regional Soviet executive committee with the active participation of the GKL has developed a plan for eliminating fuel losses and has sent copies of it to all the oil depots of the region. The GKL has insisted on establishing administrative penalties on inefficient heads of oil depots where the inspection of measuring equipment is still badly organized.

On the initiative of the Astrakhan' GKL the bureau of the Komsomol (Young Communist League) regional committee passed a resolution on "Improving the work of the regional Komsomol organizations in economizing and saving oil products." Komsomol crews have been organized in the oil depots for checking the use of and economizing on oil products. In conjunction with the GKL the YCL has worked out typical measures for organizing efficient registration, delivery and storing of fuel, and is organizing its implementation on the spot. A seminar has been organized, where the Komsomol secretaries are being instructed in the correct organization of the equipment and methods for measuring fuel and lubricating materials.

The task of the State Inspection Laboratories for Measuring Equipment is to strive for a further reduction in the losses of fuel and lubricating materials.

TECHNICAL INSTRUCTION FOR STATE INSPECTION LABORATORY WORKERS

V. V. Petropavlovskii

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pp. 56-57, February, 1961

One of the most effective methods of raising the qualifications of the GKL (State Inspection Laboratory) operating technicians is by means of technical instruction. Where the instruction is carried out regularly and is well organized, the quality of checking and inspection work improves, labor productivity is raised, and the authority of the laboratory enhanced.

However, in a number of GKLs technical studies are not organized, or else are carried out only occasionally, without a plan or a syllabus in a merely formal manner, amounting to, for instance, the reading aloud of test specifications. In such GKLs the planned production levels and timetables are not attained, labor productivity is low and the work is badly organized.

Some of the GKL heads consider that their personnel with secondary or higher technical education need not study.

Since the working conditions of the GKLs, their organization, the experience and qualifications of their personnel, the nature of the measurements they carry out in our national economy, and other factors differ considerably from each other, it would not be advisable to establish a single program of technical instruction for them.

The organization and objectives of the technical instruction in laboratories and district branches with and without measuring departments should be different.

The technical instruction plan should, as a rule, be drafted for a whole year and subdivided into months.

In the section on "Checking of measures and measuring instruments" it is recommended to dwell on the following points: assimilation of new checking methods, practice in the use of new test equipment, study of changes made in existing instructions, checking of reference instruments, checking of instruments which are not covered by standard test methods or in whose checking labor productivity is low, etc.

This section usually absorbs over half the study time. If the GKLs and the MROs (District Repair Departments) are engaged in all types of measurements, all of them should be studied by the whole of the personnel. If the GKLs and MROs have specialized groups the instruction should be conducted separately for each group of measurements.

In the section of "Checking and enforcement of standards and specifications" a study should be made of the preparations for and planning of inspection stage by stage, the organization and carrying out of the checking of measuring equipment, the summing up of test results, etc.

Subsequent studies should consist of "General inspection of measures and measuring instruments", "Control of the activity of service inspection agencies", "Study of the operational properties of gauges and measuring instruments", "Assistance in introducing new measuring equipment", "Assimilation of Rules 12-58 for various branches of industry", "Organization and establishment of temporary departments", "The work of regional instrument-making plants", and "Future development of the regional economy".

For the study of the last two sections it is desirable to invite experts from the Sovnarkhoz (Council of National Economy), from various establishments and scientific and design institutes, etc.

In carrying out this instruction it is desirable to use as much as possible visual aids, such as gauges and measuring instruments, test equipment, etc. The instruction becomes more interesting if several persons have in advance been allocated certain tasks. Thus, in studying a new specification it is advisable to make an experienced worker responsible for the carrying out of this course, and to allocate reporting on various aspects of this instruction to different workers. For instance, one could deal with the description of the instrument, another with its technical inspection, a third with its testing, a fourth with a practical demonstration of its testing, a fifth with the summarizing of the test results, the sixth with the correct use of the given measuring instrument. At the end of each course the subject of the next should be announced, together with the material to be used in preparation.

Properly organized technical instruction in the GKLs helps to improve state inspection of measuring equipment.

INTRODUCING NEW MEASURING EQUIPMENT IN THE IRKUTSK REGION

D. I. Mogilevskii

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p. 57, February, 1961

For more successful control of the enforcement of state checking, the replacement of obsolete measuring equipment and the assimilation of new automatic means of measurement, the Irkutsk GKL (State Inspection Laboratory)

in conjunction with the Sovnarkhoz (Council of National Economy) organized a commission to report on the actual condition of the measurement equipment in the region.

As a result of the commission's work, in three months there was a great improvement in the condition of the measuring equipment used in the plants.

Having a clear understanding that the assimilation of complete mechanization and automation is impossible without modern precise measuring equipment and methods of measurement, the Irkutsk GKL deals with the development of new types of instruments and makes suggestions on the assimilation of modern measuring techniques in the plants of the region. Thus, the chief engineer of the laboratory, V. Kh. Nikiforov, developed a circuit and made an attachment with a self-tuning device to an electronic potentiometer used at one of the Irkutsk plants. The plant is now installing another 15 such electronic potentiometers with attachments, which will provide measurements, recordings and adjustments of temperatures at 12 points, thus providing a considerable saving.

The laboratory has redesigned a circuit for automatic switching of blowers in firegrids of a brickyard.

A new design of a thermocouple was developed for measuring the temperature of asphalt in a plant producing it. The thermocouple is calibrated in the laboratory, it is sturdy, does not require a protective casing, is easily freed from the adhering asphalt, and provides a semiautomatic measurement of temperature by mechanical means.

On the suggestion of the laboratory several plants have introduced new, improved measuring instruments. For instance, the "Irkutskénergo" trust has replaced over 2000 obsolete electricity meters with new ones. Many establishments have supplied their laboratories with new test sets.

However, production efficiency and technological discipline require further improvement in the Irkutsk region. Hence, the basic task of the Irkutsk GKL is to provide, in conjunction with the plant laboratories, uniformity and precision of the existing gauges and measuring instruments, and to introduce into production new measuring equipment and automatic devices.

HARD-ALLOY BRACKETS

R. V. Klyuev and N. A. Karmishkin

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p. 57, February, 1961

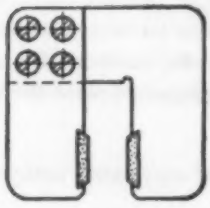

Fig. 1.

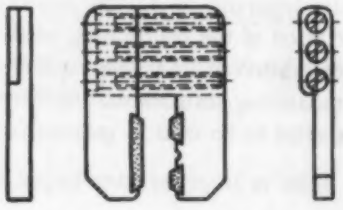

Fig. 2.

The mounting of jaws in gauge brackets made of hard alloys should be such as to direct the effort arising in checking along (Fig. 2) instead of across (Fig. 1) the axes of the fixing screws. In the former case the effect of the play in the screw holes on the correct operating dimensions of the bracket is eliminated. Such brackets have been used successfully at our plant.

INFORMATION

EXHIBITION OF DANISH ELECTRONIC MEASURING INSTRUMENTS

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pp. 58-61, February, 1961

From December 7 to 20, 1960, four Danish firms exhibited various measuring instruments at the Polytechnical Museum in Moscow. Below we give brief descriptions of the most interesting exhibits.

Instruments of the firm Brüel and Kjaer. This firm exhibited a large number of various instruments for measuring in the low-frequency range, including instruments for acoustical measurements.

Low-frequency oscillators types 1013, 1014 and 1017 based on the principle of pulsation of high-frequency oscillations (of the order of 1 Mc) provide a coverage from 2 cps to 200 kc with a frequency error of the order of 1%. These oscillators have additional frequency adjustment devices for ±5, ±50 and ±500 cps. A frequency modulation of the output signal is also provided. The output power is about 2 w with nonlinear distortions of the order of 0.5%. The output impedance of the oscillator can be set to 6, 60, 600 or 6000 ohm. An automatic output signal level-control is provided for possible load variations during testing.

For recording frequency characteristics of various low-frequency components and units a recording instrument type 2305 is used. The recording is made in ink on a chart 50 or 100 mm wide with a linear or semilogarithmic scale in rectangular coordinates. The rate of the pen displacement goes up to 2000 mm/sec (in 30 maximum speeds), the velocity of chart propulsion is from 0.0003 to 100 mm/sec (in 12 speeds). Various versions of these instruments have top measuring limits ranging from 5 mv to 100 v dc both for a linear and logarithmic scale, and provide a recording with an error not exceeding ±2% of the full scale reading.

Noise meter type 2203 is transistorized and supplied from a built-in battery. This instrument is equipped with a capacitor microphone and provides noise measurements in the range of 22 to 134 phons, with an error not exceeding ± 1 db. In conjunction with octave filters and the above-mentioned recorder this instrument can be used for analyzing audio-frequency components.

Harmonic analyzers types 2107 and 2111 are intended for use in the range of 2 cps to 35 kc with input signals of 15 μv to 1000 v. Instrument 2107 provides an analysis of voltage characteristics of any fundamental frequency in the above range, but instrument 2111 only those of a number of fixed frequencies in the range. The pointer instrument at the output of the analyzer can indicate either the effective mean or the amplitude value of the harmonic components.

Of the range of tube voltmeters made by the firm types 2405 and 2409 were exhibited. Instrument type 2405 is a wideband voltmeter with full scale readings ranging from 3 mv to 300 v and frequencies from 20 cps to 10 Mc, with an error not exceeding ±2% of the full scale. Its input impedance consists of a 5 meg resistance in parallel with a 12 μμf capacitance. Instrument type 2409 has full scale readings from 10 mv to 1000 v and frequencies of 2 cps to 200 kc. Its input impedance is 10 meg. The instrument provides measurements of the effective, mean and peak voltages (according to the position of an appropriate switch), with an error not exceeding ±2% of the full scale. The instrument's rectifier circuit for measuring effective voltages consists of diodes and resistors whose characteristics simulate the piecewise linear approximation of a square-law relationship. Either instrument can be operated as a measuring amplifier by using the appropriate output jacks.

Heterodyne voltmeter type 2005 consists of a radio-frequency tuned amplifier in the range of 20 kc to 30 Mc (and with a UHF converter type 2004 up to 230 Mc), and is intended for measuring voltages with full scale readings of 15 μv to 15 v (in 7 bands). The measurement errors do not exceed ±0.5 db for instrument 2005, and ±0.5-1 db for instrument 2004. The instrument's input impedance is 5 meg at a frequency of 100 kc and 90 kohm at a frequency of 30 Mc. The instrument is also equipped with a modulator and a loudspeaker for checking the modulated signal. The modulator has two depths of modulation, up to 30 and 100% in the range of 30 cps to 2 kc, with a modulation error of ±1 db.

Megohmmeter (teraohmmeter) type 2423 fed from ac mains provides resistance measurements from 10^5 to 10^{13} ohms (in 7 bands) with dc voltages of 10 to 100 v. The error in measuring resistances does not exceed $\pm(2 + 0.2A)\%$, where A is the scale reading. With a battery attachment type 3423 which provides a voltage up to 1000 v for feeding the measuring circuit, the top measuring limit is raised to 10^{14} ohm. The instrument can be used for measuring dc voltages up to 2 kv and currents from 10^{-11} to 10^{-4} amp with an error not exceeding ±2% of the full scale reading in each range.

The firm also exhibited an instrument type 6102 for measuring surface roughness. The instrument has a piezoelectric transducer (type MP6100 or MP0001) with a diamond needle whose radius of curvature is 12.5μ, but can be reduced to 2.5μ. Its measuring effort is 1 or 0.5 g-wt. Instrument type 6102 has 6 measuring ranges with top-scale readings of 0.1 to 30μ in arithmetic mean values of the roughness heights. The measurement error does not exceed ±10% of the top measuring limit for absolute measurements, and ±3% for comparative measurements. The transducer drive provides a needle displacement along the surface with a velocity of 3 or 1 mm/sec over any length in the range of 1.5 to 40 mm. The output pointer instrument has two additional indicators for showing the maximum and minimum deviation of the pointer. Instrument type 6102 can operate in conjunction with recording instrument type 2305 (see above), or other recording instruments or oscilloscopes, thus providing a recording of the surface profile (a profilogram).

Among the exhibited instruments and sets for strain measurements we should like to note measuring bridge type 1516 and various matching and switching units types 1530-1538. Bridge type 1516 is designed for measuring static and dynamic deformations by means of wire strain gauges with top measuring limits (depending on the bridge supply voltage and the number of strain gauges) from $25 \cdot 10^{-6}$ to $30 \cdot 10^{-3}$ relative units of deformation with an error not exceeding ±2% of the full scale. Any strain gauge can be used with a resistance of 10 to 1000 ohm. The bridge can be fed by voltages of 0.3, 1 or 3 v, either dc (for dynamic measurement with harmonic frequency components up to 100 kc) or ac up to a frequency of 3 kc (for static and dynamic measurements with harmonic frequency components up to 300 cps). The dc supplies are provided from power pack type 1535. In addition to a pointer instrument provisions are made for connecting a recording instrument or an oscilloscope. An automatic scanner type 1536 with two distributing panels type 1537 (with coupling elements) and recording instrument 2305 provide the possibility of investigating deformations in 50 points.

Instruments of the Radiometer firm. This firm exhibited various instruments for electrical measurements in the low-frequency ranges, as well as instruments for electrochemical investigations.

Bridge type CMB1 is intended for measuring capacitances in the range of 0.001 μμf to 1.1 μf. The error in measuring capacitances over 10 μμf does not exceed ±0.1% in the range of 200 cps to 5 kc, and ±0.2% in the range of 50-200 cps and 5-10 kc. The bridge measures simultaneously the loss angle tangent from 0 to 0.11, with an error of $\pm(2 + 0.5 \cdot 10^{-3})\%$. The circuit is fed from an incorporated 1000 cps RC oscillator or from an external source with a voltage of 50 v at the above frequency. For an indicating device the instrument uses a "magic eye" type tube with two luminous sectors of different sensitivities.

Bridge type GB11 is designed for measuring impedance moduli from 1 ohm to 1 meg, and angles from 0 to ±90° in the range of 25 cps to 100 kc (at 11 fixed frequencies), with an error of ±2%.

Harmonic analyzer type FRA2T has a frequency range of 30 cps to 16 kc and provides an analysis of voltages from 3 μv to 1000 v, with an error not exceeding ±0.5 db. Provisions are made for setting the tuned amplifier band at 2, 25 or 125 cps. The instrument can also measure cross-modulation and obtain frequency characteristics of tuned devices.

The nonlinear distortion meter type BKF5 has 8 ranges with top limits of 0.5 to 100% with a measurement error of 5% of the full scale plus 0.1% of the distortion coefficient. The instrument operates in a fundamental frequency range of 20 cps to 20 kc and at higher harmonics up to 60 kc. The instrument's threshold of sensitivity is 150 mv. Its input impedance consists of a resistance of 200 kohm with a series-connected capacitance of 0.1 μf.

Instrument amplifier type F33 is intended for amplifying voltages for a full deflection of pointer indicating instruments from 100 μv to 30 v in the range of 10 cps to 40 kc. Amplification errors do not exceed ±0.2 db in the range of 20 cps to 20 kc at a gain of 30 to 80 db, and ±0.4 db in the range of 15 to 20 cps and 20 to 40 kc at gains of 10 to 30 and 80 to 100 db.

Among the high-frequency electronic measuring instruments one should note bridges type QL4 and type MM1, Q-meter type QM1, standard signal generator type MS27 and tube voltmeters types RV13 and RV23.

Bridge type QL4 is intended for measuring inductances from 0.01 μh to 300 mh (in six ranges) and capacitances from 1 μμf to 0.03 μf (in three ranges), at frequencies according to the chosen band from 12 kc to 12 Mc. The measurement error is ±1.5%. A pointer galvanometer is used as the output indicating instrument. The bridge is fed from an incorporated oscillator.

Bridge type MM1 is designed to measure inductances from 0.02 μh to 55 mh (in 5 ranges) at frequencies of 30 kc to 9 Mc, and inductances from 10 mh to 1000 h (in four ranges) at mains frequency (50 cps), capacitances from 2 μμf to 0.05 μf (in three ranges) at frequencies of 300 kc to 9 Mc according to the chosen band, and from 0.05 μf to 1000 μf (in five ranges) at the mains frequency, resistances from 5 ohm to 10 meg (in six ranges) at the mains frequency. Measurement errors at high frequencies do not exceed ±2%, and at mains frequency when measuring inductances and capacitances ±4%, for resistances ±2%, and for loss angles ±5%. The loss angle tangent from 0 to 0.6 is only measured at the mains frequency. The voltage across the measured object does not exceed 4 v. The output null-indicator of the bridge consists of a "magic eye" tube. The circuit can be fed from a built-in oscillator or from the mains.

Q-meter type QM1 measures Q-factors from 30 to 250 with an error of ±5% and up to 625 with a ±10% error at frequencies of 50 kc to 70 Mc (in 8 frequency ranges). The meter incorporates a built-in main capacitor of 45-500 μμf and an auxiliary capacitor of 0-6 μμf, calibrated in 0.1 μμf. The instrument is supplied with a set of 12 screened coils with inductances ranging from 1 μh to 10 mh.

Instrument type MS27 consists of a standard signal generator with frequency and amplitude modulation, providing signals from 300 kc to 240 Mc (in 5 ranges), with an output voltage of 0.2 μv to 0.2 v for a high impedance, and half that value for a matched impedance (50 or 75 ohm). The frequency error of the output signal does not exceed ±0.5% when the built-in quartz calibrator is used. The frequency deviation in frequency modulation can be set to ±5, ±25 and ±75 kc directly or 2, 4, or 8 times that value when a multiplier is used. The output voltage amplitude error does not exceed ±2 db. The 1 kc amplitude modulation depth can be raised up to 80% with an error not exceeding ±5% for 50% depth of modulation.

Tube voltmeters RV13 and RV23 have 7 dc voltage ranges with full-scale readings of 1-1000 v, and 6 ac ranges with full-scale readings of 1-300 v. Their measurement error does not exceed ±3% of the full-scale reading. Instrument RV13 covers frequencies from 10 cps to 700 Mc with an input impedance of about 30 meg, and instrument RV23 from 20 cps to 100 Mc with an input impedance of about 60 meg. Instrument RV23 will also measure resistances from 3 ohm to 30 meg in 7 ranges, with an error not exceeding ±5%; the voltage across the measured resistor amounts to 1.5 v.

Among the exhibited electrochemical instruments we should like to note the pH-meter titrator type TTT-1, which in conjunction with a special recorder can be used as a titrograph type SBR2 and as a pH-meter type PHM23.

Instrument TTT-1 is intended for automatic electrometric titration (by the value of pH or by the chemical emf in millivolts), and for control purposes over long periods of time. The instrument has a facility for automatically disconnecting the controlling device in 5-30 sec as soon as the required value is reached. The instrument's measuring range is 1-13 pH or -600 to +1500 mv in 7 ranges each of 600 mv. Its measurement error does not exceed ±0.02 pH or ±0.5% on any of the voltage ranges.

Electronic titrograph SBR2 is used for automatic recording of titration curves (pH recorded as a function of the quantity of the reagent), or for recording the expenditure of the reagent for a fixed value of pH. The instrument is fed from the mains. The time required for recording a complete diagram on a chart 250 mm wide (in rectangular coordinates) can be set between 6 and 2000 min. The speed of chart propulsion amounts to 0.125 to 40 mm/min.

The pH-meter type PHM23 is a portable instrument supplied from ac mains and has 2 measurement ranges of 0-8 pH and 6-14 pH. Its measurement error does not exceed ±0.02 pH.

Instruments of the firm Disa Elektronik. For the purpose of measuring various mechanical and electrical variables this firm combines its double-beam universal oscilloscope type 51B00 with various electronic units and transducers which convert the measured variable into electrical signals. Among these units we should like to note the dc amplifier type 51B01, detector type 51B02 and strain gauge measuring units 51C14-51C16. Among the transducers the following deserve particular attention: the capacitative high-pressure converter type PU1A, the very high-pressure

converter type PU6A, the low-pressure converter type PU2A and the vibration converter type 51D11.

Oscilloscope 51B00 covers a frequency range of 0-500 kc on a 125mm diameter screen with a luminous grid scale. The scanning nonlinearity does not exceed 1%. The tube screen has a double covering, a yellow one with a long afterglow for visual observations, and an intense blue one for photographing. The sweep is controlled in 21 steps and by means of a continuous control, providing a coverage of from 0.08 to 10^6 cm/sec. The oscilloscope includes dc linear amplifiers with a calibrated gain and zero stabilization.

Amplifier 51B01 is designed to amplify dc, ac or pulsed voltages and consists of a wide-band dc amplifier with a chopper and a zero drift stabilization ($\pm 25\ \mu v$). Its input consists of a 1 meg resistance in parallel with 100 $\mu\mu f$; its input noise level does not exceed 50 μv. The output pulse rise time does not exceed 1.6 μsec for an input impulse. A facility is provided for adjusting the amplifier's top frequency limit from 500 cps to 700 kc.

Detector type 51B02 consists of a combination of a frequency discriminator and a dc amplifier. In conjunction with capacitative transducers in tuned circuits this amplifier provides various mechanical measurements of dynamic processes and measurements in the sphere of physiology and other sciences. The frequency discriminator works over a range of 4.4-5.6 Mc; its sensitivity amounts to 12 v change in its output dc voltage for a change of 1% in the input frequency, which amounts to a 6 v change for a 1% change in the transducer's capacitance. The incorporated dc amplifier has a frequency range of 0-400 kc, an input impedance of 1 meg, a gain of 400, and an output voltage rise time of 0.8 μsec.

Units types 51C14-51C16 are designed for measuring in conjunction with wire strain gauges and consist of a combination of bridge balancing elements and an adjustable source of a low dc voltage (from 0 to 10 v), intended to supply one to four bridge circuits.

Converter type PU1A is designed for pressures of 25-150 kg-wt/cm^2 and has 4 replaceable diaphragms. Converter type PU6A measures up to 800 kg-wt/cm^2, and converter type PU2A measures surplus pressure from -0.1 to +0.1 and from -0.1 to +17.5 kg-wt/cm^2 by means of 10 different exchangeable diaphragms either water- or air-cooled (for investigating processes in internal combustion engines).

Converter type 51D11 is designed for measuring variable gaps between the conducting surface of the object under test and the surface of an electrode of the converter in the range of fractions of a micron to several millimeters. The converter electrode is connected to a micrometer screw for static calibrations and adjustment in dynamic measurements.

Oscilloscope type 51B00 can be supplied with a camera type 51C04 for photographing onto a fixed or a uniformly moving cinema film 35 mm wide. Speed of film propulsion amounts to 1.5 to 720 mm/sec, and is controlled by a motor drive type 51C09.

The firm makes electronic contactless tachometers "Disatak" with pointer indicators for measuring the speed of shaft rotation from 4000 to 100,000 rpm. The principle of operation of these instruments consists in measuring the pulse repetition frequency obtained from the rotation of a permanent magnet fixed to the shaft. This principle makes it possible to provide remote measurements. The measurement error does not exceed ±5%. Various versions of this instrument have 1, 2 or 3 continuously measuring channels and can be supplied with signalling devices. For more precise measurements the firm manufactures photoelectric converters (transducers) type 59B20 with photocells and a transistorized amplifier, which operate in conjunction with high-speed electronic pulse counters types 59B02 and 59B03.

Counter type 59B03 operates in the range of 0 to 1 Mc. The counter includes a precision time setting device (timer) for 5 intervals from 10^{-3} to 10 sec. Its minimum input signal of any wave form is 25 $mv_{eff.}$ Its input impedance is 400 kohm. It has a six digit readout by means of luminous decade sets. The counter can also be used for measuring time intervals and frequencies. The counter type 59B02 is a five decade device with similar characteristics to the above counter and operates in the range of 0-130 kc. These counters are made up of printed circuits with electron tubes and replaceable units type 59A01 for a counting decade up to 130 kc; type 59A10 for a counting decade up to 1.2 Mc; type 59A21 for setting time intervals by means of a crystal oscillator at 6 frequencies in the range of $1\text{-}10^5$ cps (with an error of $\pm 10^{-3}$%) and other units.

Instruments of the firm Danbridge. Among its many electronic instruments this firm exhibited only ac bridges type UB3 and GZ2.

The universal bridge type UB3 can measure R–C–L and tan δ. The instrument is supplied from the mains and has a 1000 cps built-in oscillator. It can measure resistance from 0.001 ohm to 3 meg with an error of ±0.5%, capacitance from 1 μμf to 300 μf with an error of ±1%, inductance from 1 μh to 300 h with an error of ±1%, tangent of the loss angle from 0.001 to 10 with an error of ±15%.

Bridge type GZ2 is intended for measuring impedances and angles in the range of 1 ohm to 11 kohm and from 0 to ±90° with an error of ±0.5% and ±1° respectively. Measurements are carried out in the frequency range of 30 cps to 30 kc by means of an external oscillator.

The firm also exhibited various reference measures and resistance, inductance and capacitance boxes. They include three- and four-decade inductance boxes with ferrite cores types D13 measuring up to 1 h and type D14 up to 10 h with an error of 2% for 1 mh and 0.5% for 1 h. Reference double induction coils type SN1 for 0.01 and 1 h have errors of ±0.5% and ±0.2% respectively.

MEETINGS AND CONFERENCES ON MEASUREMENT TECHNIQUES

Translated from Izmeritel'naya Tekhnika, No. 2,
p. 61, February, 1961

In the State Committee for Automation in Engineering attached to the Council of Ministers of the USSR the regular session of the commission for automatic checking, control, and regulation instruments of the Scientific and Technical Council of the Committee was held on November 23, 1960.

The session heard and discussed a report by Prof. B. S. Sotskov, corresponding member of the USSR Academy of Sciences, on "Single state system for instruments and automation equipment."

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The Measurement Instruments Administration of the Committee of Standards, Measures and Measuring Instruments held a session on questions of the quality of computers, on December 8, 1960.

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At the All-Union Exhibition of the Achievements of the USSR National Economy a seminar was held on automation and the technology of testing in engineering, from December 12 to 17, 1960. The seminar was timed to coincide with an exhibition of automation and mechanization of testing in engineering, which was held in the "Engineering" pavilion of the exhibition from December 1, 1960 to February 1, 1961.

A scientific and technical conference on hydrometeorological instrument-making, organized by the Central Administration of the Hydrometeorological Service attached to the Council of Ministers of the USSR, was held from December 20 to 24, 1960. An exhibition of hydrometeorological instruments was organized for the members of the conference.

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The first All-Union conference on calorimetry was held from January 17 to 20, 1961. The conference was organized by the Commission for Chemical Thermodynamics attached to the chemistry department of the USSR Academy of Sciences, the chemistry faculty of the M. V. Lomonosov Moscow State University, the Kurnakov Institute of General and Inorganic Chemistry of the USSR Academy of Sciences, and the Committee of Standards, Measures and Measuring Instruments. The conference agenda comprised 23 papers and about 20 short reports, including papers read

by V. A. Kireev entitled "State of thermodynamic research and the need for extending calorimetric investigations in the USSR"; by B. N. Oleinik, entitled "Calorimetric work in the D. I. Mendeleev VNIIM (All-Union Scientific Research Institute of Metrology). Reproduction of a thermal unit."

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A republican scientific research conference on differential manometers and flowmeters, convened by the TsBTI (Central Bureau of Technical Information) of the Tartar Sovnarkhoz Council of National Economy), the accredited administration of the Committee attached to the Council of Ministers of the Tartar Autonomous SSR and the Tartar Republican Administration of the scientific and technical society of the instrument-making industry, was held in Kazan' on January 20-21, 1961.

At the conference 11 papers were read and excursions organized to the "Teplokontrol' " Plant, the central design bureau of thermal instruments, and the Tartar State Inspection Laboratory.

An exhibition of instruments was organized for the conference.

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The regular session of the Interdepartmental Commission of the Unified Time Service attached to the Committee of Standards, Measures and Measuring Instruments was held on February 16, 1961. At the conference a paper was read by Candidate of Technical Sciences V. I. Ermakov, director of the All-Union Scientific Research Institute of Physicotechnical and Radiotechnical measurements, entitled "The present state and future development of the Unified Time and Frequency Service of the USSR."

ERRATA

In journal No. 11, 1960, p. 5, right-hand column, line 7 from the top [translation—p. 914, end of fourth paragraph from bottom], instead of "meter, kilogram, and candle" read "meter, second, and candle."

In journal No. 1, 1961, one of the authors of the article "Complex of Metrological Work on Establishing Methods and Apparatus for Precise Measurements of High Temperatures," D. Ya. Svet, was omitted in error.

FROM FOREIGN JOURNALS

FEINGERÄTETECHNIK

No. 9, 1960

R. Schneider. On the problem of applying pneumatic measuring methods. Pneumatic devices for measuring diameters of holes, lengths, overall dimensions of articles, etc.

No. 10

Meister and Cichon. Application of automatic photoelectric methods in production and the testing of precision glass scale rules.

H. Bonnke. On the problem of a dioptric scale for eyepieces. Scale computations are cited.

E. Pippig and K. Jaworski. A beaker manometer with a range of 0.3-2.5 kg-wt/cm^2. Measurement error of 0.05% of the full scale reading.

The reproducibility of the international scale of physical and technical units and the possible errors committed in doing so.

R. Lehmann. Measurements of angles. Mechanical and optical devices for these measurements.

No. 11

H. Hertel. Systems for standardizing surface roughness and measurements made according to these systems.

No. 12

W. Gerhardt and G. Lenk. On the problem of errors in measuring surface roughness by means of a microinterferometer.

W. Bachmann. Manometer with an elastic sensing element.

Problems of defining reference and operating instruments, permissible errors, grades of accuracy. Storing of reference instruments.

ARCHIV FÜR TECHNISCHES MESSEN

No. 292, May, 1960

R. Süss. Equivalent circuit for galvanic measuring networks. The difference between measuring elements and normal galvanic sources of voltage.

C. Rohrbach. A strain-gauge measuring bridge for working at the carrier frequency of 5 kc. The principle of operation of the input devices. General schematic of the bridge, its construction, and technical data.

No. 293, June

M. Preisinger. A high-tension measuring bridge. Theory, lay-out and circuit of a modern high-tension bridge for measuring capacitance and inductance, error of ±1%.

New instruments. New universal instrument for measuring alternating currents, voltages, cos φ, frequency and resistance. Thin-wire potentiometer with an electrical control of sliders, new level-meter, etc.

No. 294, July

R. Süss. An equivalent circuit for measuring pH.

No. 295, August

H. Engelhardt. Recording gas analyzers, pt. 1. Review and classification of continuously operating gas analyzers. New types of gas analyzers for volumetric measurements. Description of gas analyzer type "Thermoflux".

H. Schwarzer. A galvanometer sensitivity regulator. Computation and circuit of the regulator.

W. Sanner. A pneumatic flow transducer. Error of measurements and error of integration are 0.6 and 0.5% respectively of the full-scale reading.

R. Gauger. Mechanical indicators. Review and circuits of variable pressure indicators.

F. Klutke. Application of glow-discharge tubes as current and voltage stabilizers.

MÉSURES ET CONTRÔLE INDUSTRIEL

No. 279, August, 1960

R. Aschen. Review of measuring instruments and techniques of measurement at ultrahigh frequency, pt. 1. Application of two-terminal networks. Resonance frequencies of two-terminal networks. Computation of the active and reactive power and raising the radiation power of a two-terminal network.

Electrical remote-control tachometers.

No. 280, September

R. Aschen. Review of measuring instruments and measuring techniques at ultrahigh frequencies. Measuring impedances of UHF networks. Instrument for measuring UHF conductivity.

Precision potentiometers.

No. 281, October

Analytical balances with a recording device. Two models of the balances with a special recording device, consisting of a system of mirrors and photocells. Maximum load 160-800 g, recording error ±1 mg and ±0.1 g.

No. 282, November

R. Jantier. Draft for new conventional notations for measuring and test instruments. The draft takes into consideration the shortcomings and problems in the existing international system.

NBS TECHNICAL NEWS BULLETIN

No. 9

The Boulder (USA) 1960 conference on standards and electronic measurements. Brief content of the papers read at the six sessions of the conference.

A mobile electronic laboratory. Brief description of the new electronic laboratory.

Comparison of Japanese and American power standards at centimeter wavelengths.

No. 10

Measuring the length of block gauges by means of an interferometer, which was originally intended for measuring the parallelism of these gauges.

No. 11

The Boulder (USA) conference on cryogenic techniques held in August, 1960. Brief contents of papers read at the nine sessions of the conference.

REVIEWS

V. N. Mil'shtein, Power Relations in Electrical Measuring Instruments.
Gosenergoizdat, Moscow, Leningrad, 1960, 312 pages, 118 illustrations. Edition of 10,000 copies.

Reviewed by K. B. Karandeev and A. F. Kotyuk

Translated from Izmeritel'naya Tekhnika, No. 2,
pp. 63;64, February

In recent years our instrument-making industry has been developing and manufacturing many types of electrical measuring instruments of various systems and for specific purposes, from direct-reading rack-mounted instruments to automatic comparison instruments and devices for measuring nonelectrical variables by means of electrical methods, in which dc and ac ratiometers are often used.

The instruments under development are often required to meet contradictory technical and operational requirements: high accuracy and reliability with the smallest possible weight and overall dimensions, minimum additional errors over a wide range of external interfering factors, ease of manufacturing the instrument, etc. In this connection, the instrument-making plants and organizations engaged in developing new instruments and improving old ones encounter great difficulties, especially in the first stages of producing the instrument, during its computation and design.

From our point of view these difficulties are mainly due to the lack of published material summing up the recent and considerable achievements of our instrument-making industry in the sphere of theory, computation and design of electrical measuring instruments. Moreover, it is obviously desirable to specify, and in certain instances, review the basic criteria for evaluating the design of instruments, criteria which should be taken into account when the instruments are being developed.

For these reasons we should welcome the appearance of V. N. Mil'shtein's original monograph, unique in the experience of world electrical instrument-making, entitled "Power Relations in Electrical Measuring Instruments," which summarizes the results of many years of the author's activity in developing G. P. Kul'bush's idea on the desirability of approaching the design of electrical measuring instruments from the power point of view. Since 1938 the author has developed on this basis original methods of computing many instruments which are being successfully used in our instrument-making industry.

Chapter I deals mainly with consideration of measuring mechanisms of electrochemical instruments as consumers of power obtained from the measured circuit. As examples for illustrating such an approach to measuring instruments power relations in ac and dc ammeters and voltmeters as well as single-phase electrodynamic wattmeters are examined.

Chapters II and III are concerned with studying power relations in moving-coil galvanometers, photoelectric galvanometric amplifiers without a feedback, and photocompensated instruments. Special attention is paid to power relations in an overdamped galvanometer, and it is shown that for $\beta > 1$ (β is degree of damping) it is possible by means of a considerable increase in the electromechanical torque and a corresponding decrease in the effect of stray torques to lower the sensitivity threshold of galvanometers and measure very small emfs.

Chapter IV solves specific problems in obtaining optimum parameters for temperature and frequency correcting circuits in electrical measuring instruments. Two ways of solving these problems on the basis of power relations had already been outlined in Chapter I.

Chapter V is devoted to the exposition of a method suggested by V. N. Mil'shtein for a quantitative evaluation of measurements in electrical networks based on the use of equivalent circuits. Here examples are also given of applying the equivalent circuit method for computing linear electrical networks with rapidly changing parameters and nonlinear networks of detecting instruments.

Chapters VI and VII deal with power relations in unbalanced bridges, in circuits with moving-coil ratiometers and rectifying instruments.

In his foreword V. N. Mil'shtein writes that he ".... does not aim at an exhaustive exposition of methods for designing instruments" and that his aim was to show methods which were most rational, from his point of view, for solving some of the most important problems encountered in designing electrical measuring instruments. This extremely modest evaluation of the aim and significance of his work is characteristic of V. N. Mil'shtein, since those who came in contact with him in his everyday life and work know his exceptional modesty, and therefore, can fully evaluate the civic and scientific achievement of this remarkable man and true scientist who, although knowing that his days were numbered, nevertheless mustered all his strength in order to complete this basic and fundamental work of outstanding importance for the further development of the theory and practice of electrical instrument-making. Only his untimely death prevented the author from continuing his research in the methods of designing instruments on the basis of a single and very important criterion, that of power relations in electrical measuring instruments. We hope that this work will be continued by the numerous pupils and disciples of V.N. Mil'shtein.

COMMITTEE OF STANDARDS, MEASURES AND MEASURING INSTRUMENTS

CHANGES IN CURRENT INSTRUCTIONS FOR TESTING MEASURES AND MEASURING INSTRUMENTS

Translated from Izmeritel'naya Tekhnika, No. 2,
p. 64, February, 1961

The Committee of Standards, Measures and Measuring Instruments has introduced as from January 1, 1961, changes in Instruction 141-55 for testing clock type indicators and in Instruction 105-55 for testing measuring machines.

Instruction 141-55 has been made to conform with the new GOST (All-Union State Standard) 577-60 for clock type indicators by means of the following changes in text.

The last paragraph of the section "Information on the device" now reads as follows: "The following types of indicators are established: I) with a displacement of the measuring rod parallel to the scale; II) butt type, with a displacement of the measuring rod perpendicular to the scale. The appearance and dimensions of these indicators are shown in drawings 2, 3 and 4," and these drawings are substituted by drawings 1, 2 and 3 respectively from GOST 577-60.

In the section "Testing" the requirements regarding the testing effort and the width of the pointer are changed. In this connection the penultimate sentence in paragraph 4b now reads: "Changes in the indicator readings due to the application of a side effort to the measuring rod are made by means of a special device (Fig. 6) which is calibrated for an effort of 300-400 g-wt; moreover, the indicator must be mounted in a rigid stand (Fig. 7) and the measuring rod must be first displaced by at least 1 mm (instead of the stand it is also possible to use the abovementioned special micrometer)", and paragraph 6a is replaced by the following: "The width of the graduations must be in the limits of 0.2-0.3 mm for indicators with scales of 3, 5 and 10 mm, and of 0.15-0.25 mm for indicators with scales of 2 mm. The width of the pointer in its part above the scale must be within the limits of 0.15-0.25 mm."

Table 2 listing tolerances is now changed and reads:

Indicator types	Tolerances in limits of						Variation in readings
	Scale section of 0.1 mm at beginning of second revolution of pointer	1 mm at any point of measurement	Total measuring interval in measuring limits of, mm				
			0–2	0–3	0–5	0–10	
	μ						
I	6	12	12	15	18	22	3
II	8	15	15	15	–	–	3

The requirements for repaired indicators which are being used are taken into consideration and their tolerances fixed over the normalized section at 12μ for type I and 15μ for type II indicators. The requirements for the special micrometer used in checking the indicator readings have been specified. The total of its error and backlash must not exceed ±0.002 mm. References to GOST 577-53 have been replaced by references to GOST 577-60. In Instruction 105-55 for testing measuring machines requirements for certain elements have been changed; in this connection the second paragraph of part 6, section III now reads: "In fixing the set screw of the micrometer head the variations in the readings must not exceed 0.003 mm"; part 9 is replaced by the following: "The double graduations of all the decimeter scale apertures must be clearly seen within ±0.5 mm from the center of the field of vision, and must completely overlap the graduations of the millimeter scale."

The second paragraph of part 16a now reads: "In rotating each setscrew the return point on the optimeter scale must be strictly observed in the limits of 0.2μ." The second paragraph of part 20b is replaced by the following:

"The parallax of the indicator with respect to the scale graduations must not exceed:

"0.05 division in the segments from 0 to +60μ and from 0 to −60μ;

"0.1 division in the segments above +60μ and below −60μ for optimeters placed on the market, and

"0.1 division in any part of the scale for optimeters in use or after having been repaired."

The first paragraph of part 21a now reads as follows:

"The glass scale of the machine with graduations of 0.1 mm is checked at the points of 20, 40, 60, 80 and 100 mm."

Soviet Journals Available in Cover-to-Cover Translation

ABBREVIATION	RUSSIAN TITLE	TITLE OF TRANSLATION	PUBLISHER	TRANSLATION BEGAN Vol.	Issue	Year
AÉ	Atomnaya énergiya	Soviet Journal of Atomic Energy	Consultants Bureau	1	1	1956
Akust. zh.	Akusticheskii zhurnal	Soviet Physics – Acoustics	American Institute of Physics	1	1	1955
	Antibiotiki	Antibiotics	Consultants Bureau	4	1	1959
Astr(on). zh(urn).	Astronomicheskii zhurnal	Soviet Astronomy–AJ	American Institute of Physics	34	1	1957
Avto(mat). svarka	Avtomaticheskaya svarka	Automatic Welding	British Welding Research Association (London)		1	1959
	Avtomatika i Telemekhanika	Automation and Remote Control	Instrument Society of America	27	1	1956
	Biofizika	Biophysics	National Institutes of Health*		1	1957
	Biokhimiya	Biochemistry	Consultants Bureau	21	1	1956
Byull. éksp(erim). biol. i med.	Byulleten' éksperimental'noi biologii i meditsiny	Bulletin of Experimental Biology and Medicine	Consultants Bureau	41	1	1959
DAN (SSSR) / Dokl(ady) AN SSSR	Doklady Akademii Nauk SSSR	The translation of this journal is published in sections, as follows:				
		Doklady Biochemistry Section	American Institute of Biological Sciences	106	1	1956
Life Sciences		Doklady Biological Sciences Sections (Includes: Anatomy, biophysics, cytology, ecology, embryology, endocrinology, evolutionary morphology, genetics, histology, hydrobiology microbiology, morphology, parasitology, physiology, zoology sections)	American Institute of Biological Sciences	112	1	1957
Life Sciences		Doklady Botanical Sciences Sections (Includes: Botany, phytopathology, plant anatomy, plant ecology, plant embryology, plant physiology, plant morphology sections)	American Institute of Biological Sciences	112	1	1957
Chemical Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Chemical Technology	Consultants Bureau	106	1	1956
Chemical Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Chemistry	Consultants Bureau	106	1	1956
Chemical Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Physical Chemistry	Consultants Bureau	112	1	1957
Earth Sciences		Doklady Earth Sciences Sections (Includes: Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, permafrost sections)	American Geological Institute	124	1	1959
Earth Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Geochemistry	Consultants Bureau	106-123	1-6	1957-1958
Earth Sciences		Proceedings of the Academy of Sciences of the USSR, Sections: Geology	Consultants Bureau	106-123	1-6	1957-1958
Mathematics	Doklady Soviet Mathematics		The American Mathematics Society	131	1	1961
Physics		Soviet Physics–Doklady (Includes: Aerodynamics, astronomy, crystallography, cybernetics and control theory, electrical engineering, energetics, fluid mechanics, heat engineering, hydraulics, mathematical physics, mechanics, physics, technical physics, theory of elasticity sections)	American Institute of Physics	106	1	1956
Physics		Proceedings of the Academy of Sciences of the USSR, Applied Physics Sections (does not include mathematical physics or physics sections)	Consultants Bureau	106-117	1	1956-1957
Derevoobrabat. prom-st'.	Derevoobrabatyvayushchaya promyshlennost'	Wood Processing Industry	Timber Development Association (London)		9	1959
	Élecktrosvyaz	Telecommunications	Massachusetts Institute of Technology*		1	1957
Éntom(ol). oboz(renie)	Éntomologicheskoe obozrenie	Entomological Review	American Institute of Biological Sciences	38	1	1959
Farmakol. (i) toksikol(ogiya)	Farmakologiya i toksikologiya	Pharmacology and Toxicology	Consultants Bureau	20	1	1957
FMM	Fizika metallov i metallovedenie	Physics of Metals and Metallography	Acta Metallurgica*	5	1	1957
Fiziol. zhurn. SSSR (im. Sechenova)	Fiziologicheskii zhurnal im. I. M. Sechenova	Sechenov Physiological Journal USSR	National Institutes of Health*		1	1957
Fiziol(ogiya) rast.	Fiziologiya rastenii	Plant Physiology	American Institute of Biological Sciences	4	1	1957
	Geokhimiya	Geochemistry	The Geochemical Society		1	1958
FTT	Fizika tverdogo tela	Soviet Physics–Solid State	American Institute of Physics	1	1	1959
Izmerit. tekh(nika)	Izmeritel'naya tekhnika	Measurement Techniques	Instrument Society of America		1	1959
Izv. AN SSSR, O(td). Kh(im). N(auk)	Izvestiya Akademii Nauk SSSR: Otdelenie khimicheskikh nauk	Bulletin of the Academy of Sciences of the USSR: Division of Chemical Sciences	Consultants Bureau		1	1952

continued

Izv. AN SSSR, O(td). T(ekhn). N(auk): Met(all). i top.	(see Met. i top.)				
Izv. AN SSSR Ser. fiz(ich).	Izvestiya Akademii Nauk SSSR: Seriya fizicheskaya	Bulletin of the Academy of Sciences of the USSR: Physical Series	Columbia Technical Translations	1	1954
Izv. AN SSSR Ser. geofiz.	Izvestiya Akademii Nauk SSSR: Seriya geofizicheskaya	Bulletin (Izvestiya) of the Academy of Sciences USSR: Geophysics Series	American Geophysical Union	1	1954
Izv. AN SSSR Ser. geol.	Izvestiya Akademii Nauk SSSR: Seriya geologicheskaya	Izvestiya of the Academy of Sciences of the USSR: Geologic Series	American Geological Institute	1	1958
Kauch. i rez.	Kauchuk i rezina	Soviet Rubber Technology	Research Association of British Rubber Manufacturers	18	1 1959
	Kinetika i kataliz	Kinetics and Catalysis	Consultants Bureau	1	3 1960
	Koks i khimiya	Coke and Chemistry USSR	Coal Tar Research Association (Leeds, England)		1 1958
Kolloidn. zh(urn).	Kolloidnyi zhurnal	Colloid Journal	Consultants Bureau	14	1 1952
	Kristallografiya	Soviet Physics – Crystallography	American Institute of Physics	2	1 1957
Metalov. i term. obrabot. metal.	Metallovedenie i termicheskaya obrabotka metallov	Metal Science and Heat Treatment of Metals	Acta Metallurgica	6	1 1958
	Metallurg	Metallurgist	Acta Metallurgica		1 1957
Met. i top.	Metallurgiya i topliva	Russian Metallurgy and Fuels	Eagle Technical Publications		1 1960
Mikrobiol.	Mikrobiologiya	Microbiology	American Institute of Biological Sciences	26	1 1957
OS	Optika i spektroskopiya	Optics and Spectroscopy	American Institute of Physics		6 1959
	Pochvovedenie	Soviet Soil Science	American Institute of Biological Sciences		1 1958
	Priborostroenie	Instrument Construction	British Scientific Instrument Research Association		1 1959
Pribory i tekhn. éks(perimenta)	Pribory i tekhnika éksperimenta	Instruments and Experimental Techniques	Instrument Society of America		1 1957
Prikl. matem. i mekh.	Prikladnaya matematika i mekhanika	Applied Mathematics and Mechanics	American Society of Mechanical Engineers		1 1958
PTÉ	(see Pribory i tekhn. éks.)				
	Problemy Severa	Problems of the North	National Research Council of Canada		
Radiotekh.	Radiotekhnika	Radio Engineering	Massachusetts Institute of Technology*	12	1 1957
Radiotekh. i élektronika	Radiotekhnika i élektronika	Radio Engineering and Electronics	Massachusetts Institute of Technology*	2	1 1957
	Stanki i instrument	Machines and Tooling	Production Engineering Research Assoc.		1 1959
	Stal'	Stal (In English)	Iron and Steel Institute		1 1959
Stek. i keram.	Steklo i keramika	Glass and Ceramics	Consultants Bureau	13	1 1956
Svaroch. proiz-vo	Svarochnoe proizvodstvo	Welding Production	British Welding Research Association		4 1959
Teor. veroyat. i prim.	Teoriya veroyatnostei i ee primenenie	Theory of Probability and Its Applications	Society for Industrial and Applied Mathematics		1 1956
Tsvet. Metally	Tsvetnye metally	Nonferrous Metals	Primary Sources		1 1960
UFN	Uspekhi fizicheskikh Nauk	Soviet Physics – Uspekhi (partial translation)	American Institute of Physics	66	1 1958
UKh	Uspekhi khimii	Russian Chemical Reviews	The Chemical Society (London)		1 1960
UMN	Uspekhi matematicheskikh nauk	Russian Mathematical Surveys	London Mathematical Society	15	1 1960
Usp. fiz. nauk	(see UFN)				
Usp. khim(ii)	(see UKh)				
Usp. matem. nauk	(see UMN)				
Usp. sovr. biol.	Uspekhi sovremennoi biologii	Russian Review of Biology	Oliver and Boyd	48	1959
Vest. mashinostroeniya	Vestnik mashinostroeniya	Russian Engineering Journal	Production Engineering Research Assoc.	4	1959
Vop. gem. i per. krovi	Voprosy gematologii i perelivaniya krovi	Problems of Hematology and Blood Transfusion	National Institutes of Health*	1	1957
Vop. onk.	Voprosy onkologii	Problems of Oncology	National Institutes of Health*	1	1957
Vop. virusol.	Voprosy virusologii	Problems of Virology	National Institutes of Health*	1	1957
Zav(odsk). lab(oratoriya)	Zavodskaya laboratoriya	Industrial Laboratory	Instrument Society of America	25	1 1959
ZhAKh Zh. anal(it). khimii	Zhurnal analiticheskoi khimii	Journal of Analytical Chemistry USSR	Consultants Bureau	7	1 1952
ZhETF Zh. éksperim. i teor. fiz.	Zhurnal éksperimental'noi i theoreticheskoi fiziki	Soviet Physics–JETP	American Institute of Physics	28	1 1955
ZhFKh Zh. fiz. khimii	Zhurnal fizicheskoi khimii	Russian Journal of Physical Chemistry	The Chemical Society (London)		7 1959
ZhMÉI Zh(urn). mikrobiol. épidemiol. i immunobiol.	Zhurnal mikrobiologii, épidemiologii i immunobiologii	Journal of Microbiology, Epidemiology and Immunobiology	National Institutes of Health*		1 1957
ZhNKh Zh(urn). neorgan(ich). khim(ii)	Zhurnal neorganicheskoi khimii	The Russian Journal of Inorganic Chemistry	The Chemical Society (London)		1 1959
ZhOKh Zh(urn). obshch(ei) khimii	Zhurnal obshchei khimii	Journal of General Chemistry USSR	Consultants Bureau	19	1 1949
ZhPKh Zh(urn). prikl. khimii	Zhurnal prikladnoi khimii	Journal of Applied Chemistry USSR	Consultants Bureau	23	1 1950
ZhSKh Zh(urn). strukt. khimii	Zhurnal strukturnoi khimii	Journal of Structural Chemistry	Consultants Bureau	1	1 1960
ZhTF Zh(urn). tekhn. fiz.	Zhurnal teknicheskoi fiziki	Soviet Physics–Technical Physics	American Institute of Physics	26	1 1956
Zh(urn). vyssh. nervn. deyat. (im. Pavlova)	Zhurnal vysshei nervnoi deyatel'nosti (im. I. P. Pavlova)	Pavlov Journal of Higher Nervous Activity	National Institutes of Health*		1 1958

*Sponsoring organization. Translation through 1960 issues is a publication of Pergamon Press.

SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET TECHNICAL PERIODICALS

AN SSSR	*Academy of Sciences, USSR*
FIAN	*Physics Institute, Academy of Sciences USSR*
GITI	*State Scientific and Technical Press*
GITTL	*State Press for Technical and Theoretical Literature*
GOI	*State Optical Institute*
GONTI	*State United Scientific and Technical Press*
Gosénergoizdat	*State Power Press*
Gosfizkhimizdat	*State Physical Chemistry Press*
Goskhimizdat	*State Chemistry Press*
GOST	*All-Union State Standard*
Gostekhizdat	*State Technical Press*
GTTI	*State Technical and Theoretical Press*
IAT	*Institute of Automation and Remote Control*
IF KhI	*Institute of Physical Chemistry Research*
IFP	*Institute of Physical Problems*
IL	*Foreign Literature Press*
IPF	*Institute of Applied Physics*
IPM	*Institute of Applied Mathematics*
IREA	*Institute of Chemical Reagents*
ISN (Izd. Sov. Nauk)	*Soviet Science Press*
IYap	*Institute of Nuclear Studies*
Izd	*Press (publishing house)*
LÉTI	*Leningrad Electrotechnical Institute*
LFTI	*Leningrad Institute of Physics and Technology*
LIM	*Leningrad Institute of Metals*
LITMiO	*Leningrad Institute of Precision Instruments and Optics*
Mashgiz	*State Scientific-Technical Press for Machine Construction Literature*
MGU	*Moscow State University*
Metallurgizdat	*Metallurgy Press*
MOPI	*Moscow Regional Pedagogical Institute*
NIAFIZ	*Scientific Research Association for Physics*
NIFI	*Scientific Research Institute of Physics*
NIIMM	*Scientific Research Institute of Mathematics and Mechanics*
NIKFI	*Scientific Institute of Motion Picture Photography*
NKTM	*People's Commissariat of the Heavy Machinery Industry*
Obrongiz	*State Press of the Defense Industry*
OIYaI	*Joint Institute of Nuclear Studies*
ONTI	*United Scientific and Technical Press*
OTI	*Division of Technical Information*
OTN	*Division of Technical Science*
RIAN	*Radium Institute, Academy of Sciences of the USSR*
SPB	*All-Union Special Planning Office*
Stroiizdat	*Construction Press*
URALFTI	*Ural Institute of Physics and Technology*
TsNIITMASh	*Central Scientific-Research Institute of Technology and Machinery*
VNIIM	*All-Union Scientific Research Institute of Metrology*

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us — *Publisher.*

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